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TROPHIC CLASSIFICATION OF TENNESSEE VALLEY AREA RESERVOIRS DERIVED FROM LANDSAT MULTISPECTRAL SCANNER DATA

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ABSTRACT

This study evaluated the application of Landsat multispectral scanner (MSS) imagery for assessing the trophic status of the major lakes and reservoirs in the Tennessee Valley.

Ground truth water quality data collected by the Environmental Protection Agency during the 1973 National Eutrophication Survey (NES) at 35 reservoirs in the greater Tennessee Valley region were subjected to cluster and principal component data analyses to develop a trophic state index for the reservoirs. Each reservoir's trophic state index was defined by its relative position on a first principal component axis. Water quality characteristics selected as trophic indicators used in the cluster analysis and principal component analysis were chlorophyll a, conductivity, total phosphorus, total organic nitrogen, the inverse of the Secchi disc depth, and the yield of an algal assay procedure.

Landsat MSS data from four different dates were extracted from computer tapes using a semi-automated digital data handling and analysis system at the University of Wisconsin - Madison. Reservoirs were extracted from the surrounding land matrix by using a Band 7 density level slice of 3; and descriptive statistics to include mean, variance, and ratio between bands for each of the four bands were calculated.

Significant correlations (>0.80) between the MSS statistics and many trophic indicators were identified. Regression models were developed to predict reservoir eutrophication using MSS statistics as the independent variables and the trophic state index, developed from ground truth, as the dependent variable in each frame. Regression models were also developed to predict Secchi disc depth, conductivity, and total phosphorus. The models gave significant estimates of each reservoir's trophic state as defined by its trophic state index and explained in all four Landsat frames at least 85 percent (R^2) of the variability in the data. Each Landsat frame had its own unique models which were not practically applicable on other dates.

To illustrate the spatial variations within reservoirs as well as the relative variations between reservoirs, a table-look-up elliptical classification was used in conjunction with each reservoir's trophic state index to classify each reservoir on a pixel-by-pixel basis and produce color-coded thematic representations.

Although the need for ground truth information on water quality places a restriction on the use of Landsat MSS data for the prediction of trophic state, such data still has value in regions where there are many lakes or reservoirs within a single MSS frame. Under such circumstances the collection of ground truth from a small number of "bench mark" lakes for the development of regression models would result in considerable cost savings.

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ABBREVIATIONS

bpi	bit-per-inch
CCT	computer compatible tapes
DCS	data collection system
deg	degrees
DN	digital number
EPA	Environmental Protection Agency
EROS	Earth Resources Observation System
ERTS	Earth Resources Technology Satellite
IFOV	instantaneous field of view
km	kilometer
Landsat	Land Satellite
m	meters
MB_i	mean raw reflectance value for band i
mg/l	milligrams per liter
MSS	multispectral scanner
NASA	National Aeronautics and Space Administration
nm	nanometers
NMR	normalized mean rank
NT-SYS	numerical taxonomy system
PC1	principal component, trophic state index
pixel	picture element
RB_i	ratio of reflectance values between band i and band i + 1
RBV	return beam vidicon
revs	revolutions
SAS	statistical analysis system
Seasat	Sea Satellite
STORET	water quality data storage and retrieval system of the Environmental Protection Agency
TVA	Tennessee Valley Authority
μmhos/cm	micro mhos per centimeter
VB_i	variance of reflectance values for band i
VRB_i	variance of the ratio of the reflectance values between band i and band i + 1

ACKNOWLEDGEMENTS

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INTRODUCTION

The science of remote sensing, that is the collection of information about an object from a distance, is a rapidly developing water quality monitoring tool that is expected to complement in situ sampling and analysis. Remote sensing has rapidly progressed from a purely qualitative water quality monitoring tool to one which permits quantitative prediction of certain water quality characteristics over large areas based on limited ground observations. Some rather obvious benefits of remote sensing are the ability to present a synoptic pictorial representation of an extensive area as opposed to a specific location, to survey vast areas in a very short time, and to observe at a later time information that was not fully realized or being sought at the time the data were collected.

Most past Landsat eutrophication studies (Boland, 1976; Scarpace et al., 1978) have focused on natural lakes. In this study, reservoirs were investigated. The relatively short hydraulic retention times of most reservoirs ensure that responses to changes in waste loads will be detected in a matter of years rather than the decades required for most naturally formed lakes. Most nutrient loading trophic state models have been developed using data from natural lakes in the northeastern United States and Europe (Vallenweider, 1968; Rast and Lee, 1978). Reservoirs have relatively high flushing rates and respond differently to nutrient inputs than do natural lakes with relatively lower flushing rates.

In this study we have investigated the application of Landsat multispectral scanner imagery to assess water quality conditions in the Tennessee Valley region, with particular emphasis on the determination of the trophic status of the major reservoirs in the Valley. The purpose of this project was to develop and demonstrate technologies which improve the effectiveness and efficiency of water quality monitoring programs.

LANDSAT SATELLITE CHARACTERISTICS

The Landsat system was developed by the National Aeronautics and Space Administration (NASA) to help meet the increasing demand for man to manage the earth's limited natural resources. Data gathered by the Landsat has been applied to studies in the fields of geology, cartography, geography, land management, forestry, hydrology, and many others.

This series of satellites began with the launch of Earth Resources Technology Satellite 1 (ERTS) in July 1972. This experimental satellite proved the applicability of monitoring the earth's surface from space, and led to the launch of ERTS 2 in January 1975. It was after the successful launch of ERTS 2 that the new name Land Satellite (Landsat) was adopted. The new name distinguishes these satellites from the Seasat series of earth observation satellites.

Landsat 1 was turned off in January 1978. Landsat 2 continues to operate and Landsat 3 was launched in March of 1978. Plans are currently being developed for the fourth Landsat with a scheduled 1981 launch. Imagery used in this study was obtained by Landsat 1 or Landsat 2.

Landsat satellites are launched into sun-synchronous near-polar orbits at an altitude of approximately 900 km (540 mi) (table 1). This type of orbit ensures repeatable sun-illumination conditions for any particular date from year to year.

The satellites cross the equator every 103 minutes thus completing 14 orbits in 24 hours. Therefore, the next westward track of data for any orbit is acquired at the same sun time the following day (figure 1). The earth rotates 2,760 km (1,650 mi) under the satellite at the equator during each orbit. The coverage width of each orbit pass is 185 km (115 mi) and the distance between adjacent orbits at the equator is 159 km (95 mi). Complete earth coverage is, therefore, completed by each satellite every 18 days. Landsat 2 was launched so that its orbit follows Landsat 1 by 9 days. Landsat 2 and 3 also provide 9-day coverage.

The instrumentation of Landsats 1 and 2 consists of two imaging systems, the multispectral scanner (MSS) and the return beam vidicon (RBV). Also on board are the data collection system (DCS) receiver and transmitter, and two wide band video tape recorders (figure 2). Only data from the MSS system was used in this study and need be considered.

The MSS is a line-scanning radiometer which collects data by creating images of the earth's surface in four spectral bands simultaneously. Radiation coming from the surface of the earth and its atmosphere is recorded as an analog signal which is converted to values of from 0-63. The numbers represent brightness values (BV), the amount of electromagnetic energy reflected from an area on the earth's surface in one wave length band.

The MSS scans the earth's surface from west to east (figure 3). Twenty-four detectors are used to record six lines of data (figure 4) in each of the four wave length bands (table 2).

Table 1: Characteristics of the Landsat orbit

Orbital Parameter	Actual Orbit
Semi-major axis	7285.82 km
Inclination	99.114 deg
Period	103.267 min
Eccentricity	.0006
Time of equatorial crossing	9:42 a.m.
Coverage cycle	18 days
Duration of cycle	251 revs
Distance between adjacent tracks at the equator	159.38 km
Distance between successive tracks at the equator	2,760 km
Altitude	880 - 940 km

Table 2: Spectral wave lengths (bands) of Landsat multispectral scanner

Band 4	Visible green	0.5 - 0.6μm
Band 5	Visible red	0.6 - 0.7μm
Band 6	Invisible reflected IR	0.7 - 0.8μm
Band 7	Invisible reflected IR	0.8 - 1.1μm

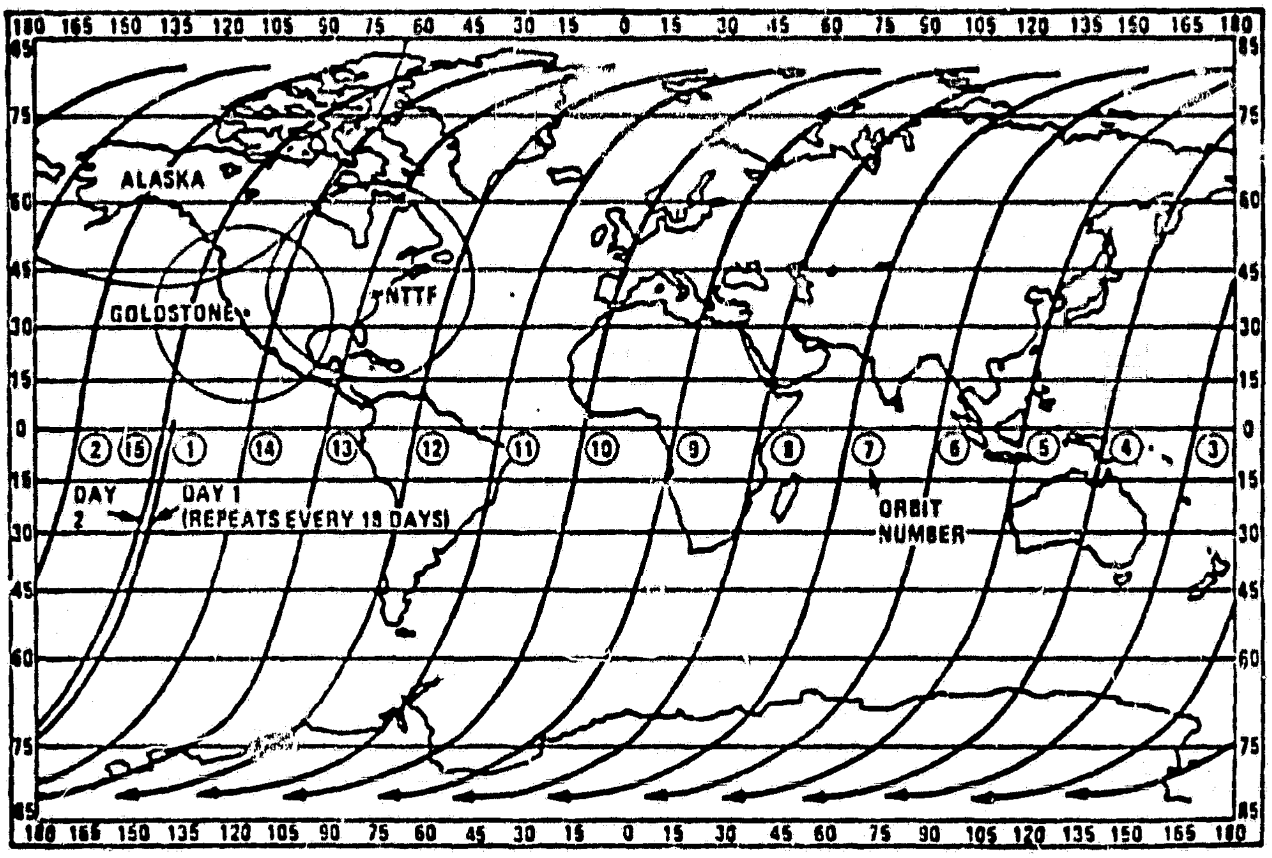
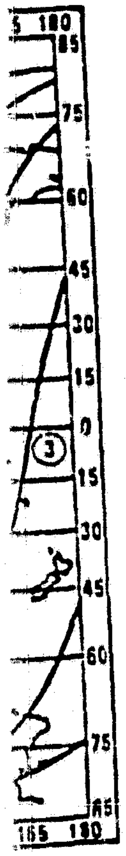


Figure 1: Landsat orbital tracks for one day of coverage. From NASA Landsat Data Users Handbook.



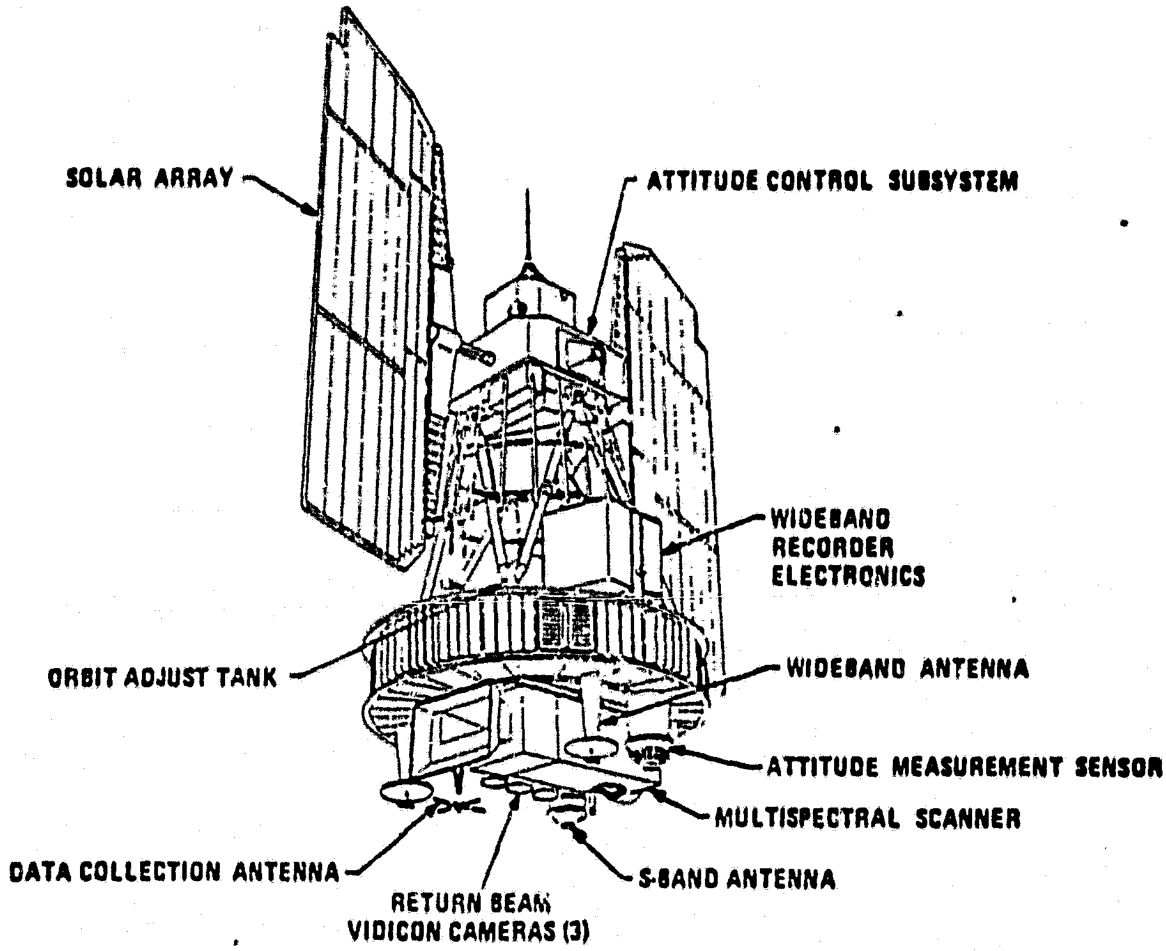


Figure 2: Landsat configuration. From NASA Landsat Data Users Handbook.

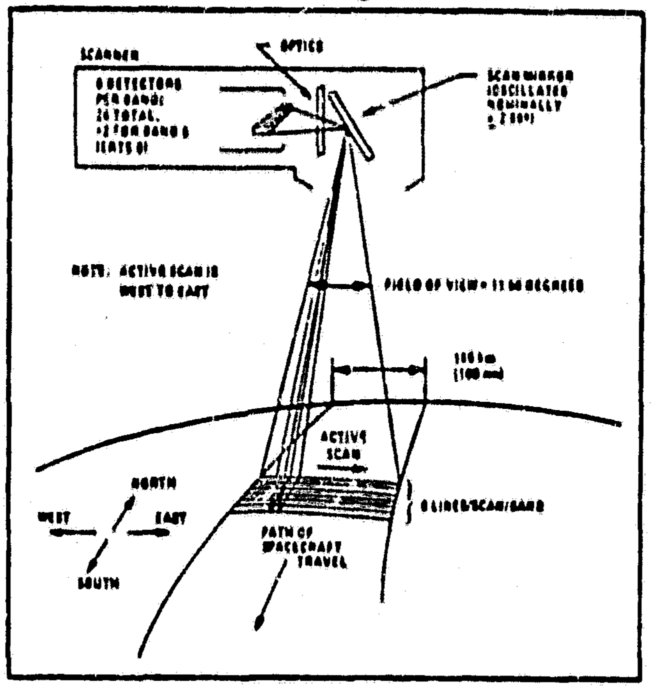


Figure 3: Scanning arrangement of MSS. From NASA Landsat Data Users Handbook.

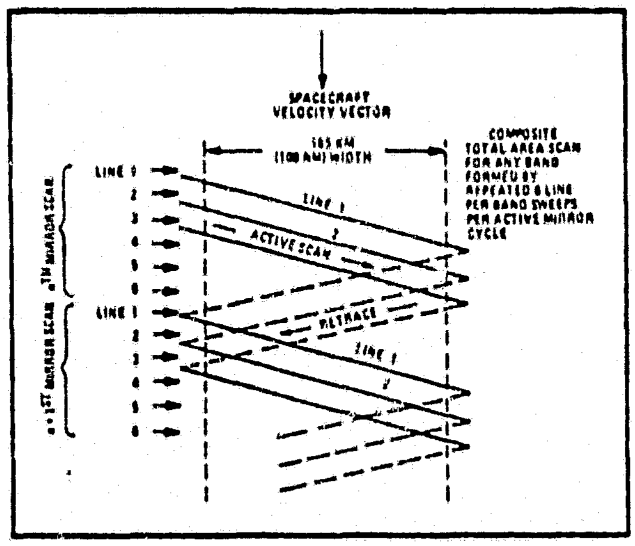


Figure 4: Scanning pattern of MSS on the earth's surface. From NASA Landsat Data Users Handbook.

During a scan, the signal is sampled every 9.95 microseconds. For each band, approximately 3,300 samples are taken along a 185 km line (figure 4). Thus, the instantaneous field of view (IFOV) of 79 m by 79 m moves about 56 m on the ground between each sample. The individual radiation measurements must be arranged on an image in a manner that preserves spatial relationships. Thus, the measurements are assigned dimensions of 56 m by 79 m so that geometric distortions are not introduced. The 56 m by 79 m area is called a Landsat picture element or pixel.

Landsat MSS imagery is placed in the public domain and is available as either photographic products or computer compatible magnetic tape.

For the user to locate the area of his interest, the continuous image of the MSS has been divided along the orbit path (north to south) into sections equal to the east-west width of the MSS scan, 185 km (115 mi). This division is always made as near to the same location as possible, thus creating nominal scenes of Landsat data. These scenes are assigned a unique identifying number corresponding to the orbit path and the east-to-west row of scenes (figure 5).

Photographic products available include black and white prints of individual Landsat bands. These products cover one nominal scene of imagery 185 km by 185 km and are available in a variety of scales. Also available are false color infrared composites of selected scenes. These products utilize band 4, 5, and 7 to create photographically the false color image.

Landsat computer compatible tapes (CCT) are available in one-tape, 1,600 bit-per-inch (bpi) or in two-tape 800 bpi format.

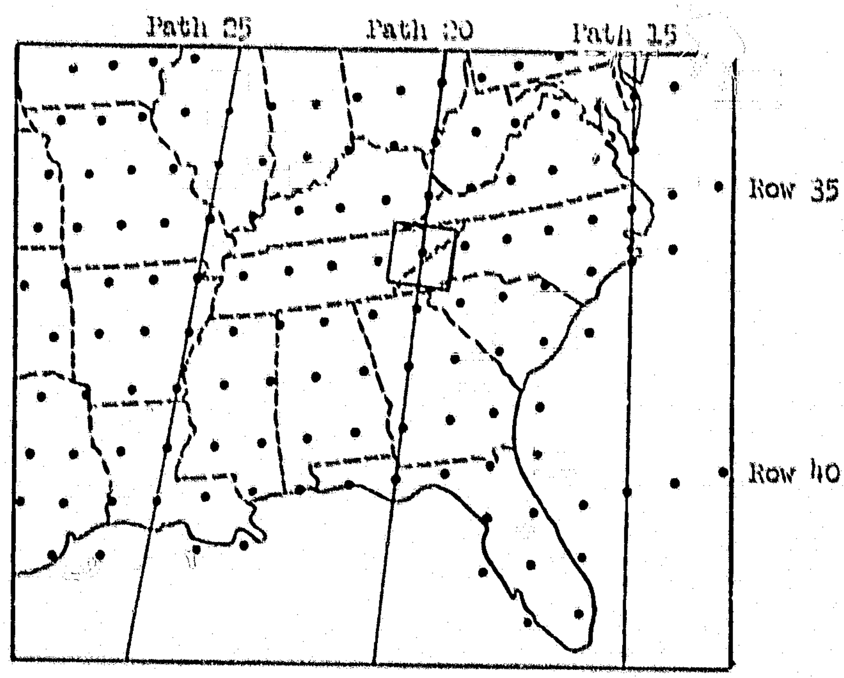


Figure 5: Nominal scenes for Landsat imagery

DESCRIPTION OF THE GREATER TENNESSEE VALLEY REGION STUDY AREA

This study focuses on the greater Tennessee Valley region of the southeastern United States. The drainage basin of the Tennessee River encompasses a land-locked area of about 106,000 sq. km (40,910 sq. mi) in the southeastern United States, including parts of Tennessee, Alabama, North Carolina, Virginia, Georgia, Kentucky, and Mississippi.

The Tennessee River system has almost 61,200 km (38,000 mi) of streams and rivers. Lakes and reservoirs have over 2,600 sq. km (1,015 sq. mi) of surface water and more than 17,700 km (11,000 mi) of shoreline. The watershed is characterized by rugged mountains and green forests in the eastern portion of the Valley and rolling hills, open fields, and woodlands in the west. From Mount Mitchell, North Carolina, in the east, to Paducah, Kentucky, in the west, the topography ranges from 2,037 m (6,684 ft) to 90 m (300 ft) above sea level.

The Tennessee River Valley, one of the wettest regions of the United States, receives about 132 cm (52 in) of rainfall a year. March is usually the wettest month, and September or October, the driest. The climate is mild and humid with an average mean air temperature of about 15°C (59°F) and an average monthly humidity of 66 to 84 percent.

About 59 percent of the Tennessee River basin is forested; about 38 percent is open land and pasture; and 2 percent is covered by water. Approximately 4 million people live in the Tennessee River watershed. Over 85 percent of this population resides in towns and cities or in the nonfarm rural areas surrounding population centers; fewer than 15 percent now live on farms. About 40 percent of the population lives in six population centers: Asheville, North Carolina; Bristol-Johnson City-Kingston, Tennessee; Knoxville-Oak Ridge, Tennessee; Chattanooga, Tennessee; Huntsville-Decatur, Alabama; and Florence-Sheffield-Tuscumbia, Alabama.

The reservoirs examined in this study are located in parts of Tennessee, Alabama, Georgia, Kentucky, and North Carolina (figure 6). Superimposed on this figure of the greater Tennessee Valley region are the approximate ground area coverages of Landsat scenes corresponding to Path 20, Row 35 & 36 (figure 5) from which information relating to reservoir trophic status was extracted. This region was selected because of the many reservoirs and the availability of ground truth water quality data and Landsat imagery.

Ground truth data for the reservoirs incorporated in this study were collected by the U.S. Environmental Protection Agency (EPA) during their National Eutrophication Survey (NES) of 1973. The study reservoirs are listed in table 3 with information of the morphometry and hydrology of selected reservoirs. NES-sampled reservoirs are the first 35 listed; the last 14 listed reservoirs were outside the scope of the NES, but are included because they are of interest in using Landsat to assess their trophic state.

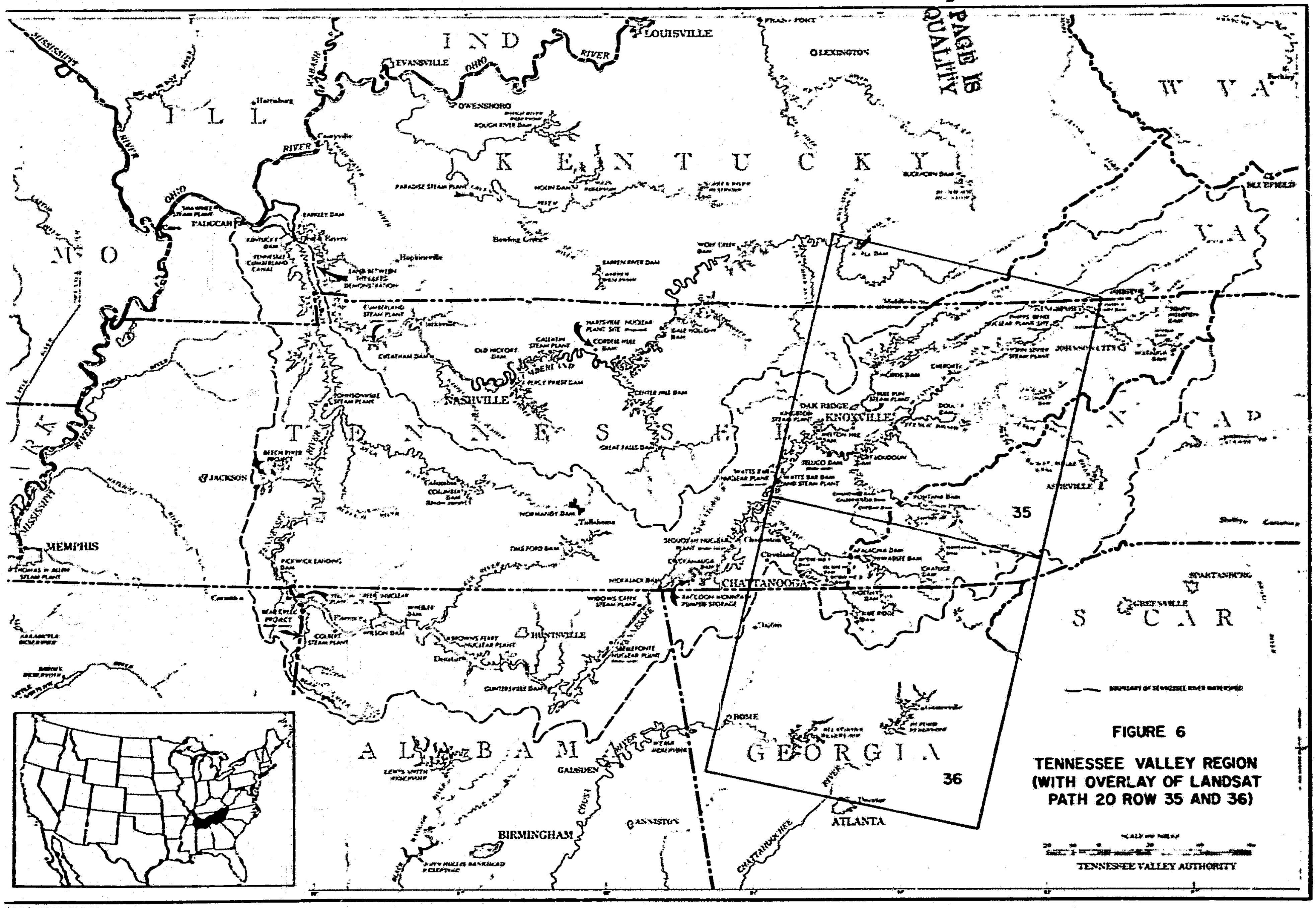


FIGURE 6

TENNESSEE VALLEY REGION
(WITH OVERLAY OF LANDSAT
PATH 20 ROW 35 AND 36)

Table 3

MORPHOMETRY AND HYDROLOGY OF 35 RESERVOIRS IN THE GREATER TENNESSEE VALLEY REGION SAMPLED DURING THE NATIONAL EUTROPHICATION SURVEY OF 1973

Reservoir Name	Identification Number	Area (km^2)	Mean Depth (m)	Max. Depth (m)	Volume (m^3) x 10^6	Retention Time (days)
Allatoona	GA 1	48	9.4	45.1	451	103
Barkley	TN 2	64	4.6	21.0	296	3
Barren	KY 3	82	12.3	>18.6	1005	342
Blue Ridge	GA 4	13	18.4	>43.0	247	176
Boone	TN 5	18	13.3	39.6	239	41
Burton	GA 6	11	11.9	>30.05	134	161
Chatuge	GA 7	29	10.6	36.9	307	269
Cheatham	TN 8	30	4.3	13.1	130	2
Cherokee	TN 9	123	14.9	49.7	1901	178
Chickamauga	TN 10	143	5.4	20.0	912	9
Cumberland	KY 11	203	24.2	>56.7	4928	226
Dale Hollow	KY 12	109	14.4	>36.0	1569	438
Douglas	TN 13	123	14.1	38.7	1819	108
Fontana	NC 14	43	41.3	134.1	1782	179
Fort Loudoun	TN 15	59	7.6	25.3	485	13
Great Falls	TN 16	12	5.1	21.9	63	8
Guntersville	AL 17	275	4.6	20.8	1256	12
Hiwassee	NC 18	25	21.3	>67,4	541	116
Junaluska	NC 19	81	5.6	>7.0	4.5	13
Kentucky	KY 20	649	5.2	26.9	7560	22
Nickajack	TN 21	42	7.1	39.3	311	3
Nottley	GA 22	17	13.1	>36.6	227	231
Old Hickory	TN 23	91	5.6	17.6	510	11
Percy Priest	TN 24	57	8.5	30.5	488	139
Pickwick	AL 25	174	6.5	26.5	1140	8
Reelfoot	TN 26	36	1.4	4.9	50	-
Santeetlah	NC 27	12	16.8	65.0	195	161
Sidney Lanier	GA 28	167	19.5	54.9	3149	584
South Holston	TN 29	31	26.4	74.4	942	388

Table 3

MORPHOMETRY AND HYDROLOGY OF 35 RESERVOIRS IN THE GREATER TENNESSEE VALLEY REGION SAMPLED DURING THE NATIONAL EUTROPHICATION SURVEY OF 1973 (Continued)

Reservoir Name	Identification Number	Area (km^2)	Mean Depth (m)	Max. Depth (m)	Volume (m^3) x 10^6	Retention Time[a] (days)
Times Ford	TN 30	43	15.2	43.6	750	300
Waterville	NC 31	1.4	22.7	54.0	31	15
Watts Bar	TN 32	158	7.9	32.0	1449	18
Weiss	TN 33	122	2.8	15.2	342	16
Wilson	AL 34	63	12.5	34.3	783	6
Woods	TN 35	16	5.7	-	92	85
Carters	1					
Chilhowee	2					
Hartwell	3					336
Laurel	4					
Melton Hill	5	2	6.4	21.7	148	12
Nantahala	6	0.6	26.4	>39.0	171	
Nolichucky	7	0.3	3.3	19.0	8	75
Norris	8	14	18.2	>30.0	2525	
Parksville	9	0.8	13.9		107	30
Rabun	10					
Thorpe	11	0.6	14.8	>22.0	87	
Toxaway	12					
Tuckasegee	13					
Tugaloo	14					

[a]Ratio of reservoir volume to average discharge

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GROUND TRUTH WATER QUALITY DATA COLLECTION

All the 35 NES reservoirs were sampled three times (spring, summer, and fall) during the 1973 calendar year by pontoon-equipped helicopter-borne sampling teams. The helicopters were equipped with in situ sensors for the measurement of conductivity, temperature, optical transmissivity, dissolved oxygen, pH, and water depth. Samples for algal identification, chlorophyll a, and nutrients were collected using a submersible pump. Additional equipment included an echo sounder, 30 cm Secchi disc, and water sampling equipment. Specific details of sample collection and methods of laboratory analyses are found in National Eutrophication Survey Methods (1975).

Most of the reservoirs surveyed were chosen on the basis of actual or potential eutrophication problems, with the result that this investigation does not universally represent the normal distribution of reservoirs in the Tennessee Valley, with respect to trophic state, and is biased or weighted toward reservoirs that are often referred to as "eutrophic." In general only reservoirs of one km^2 or larger and mean hydraulic retention times of at least two weeks were considered; however, these selection criteria were waived for reservoirs of particular interest. Sampling sites in each reservoir were selected primarily to attempt to define the character of the reservoir as a whole rather than specific areas or embayments of the reservoirs and chosen to reflect the deepest portion of each major basin in a reservoir. The number of sampling sites varied for different reservoirs, ranging from one (Junaluska Reservoir) to seventeen (Kentucky Reservoir).

Data were made available through the Environmental Protection Agency's water quality data storage and retrieval system (STORET).

EUTROPHICATION AND TROPHIC STATE INDICATORS

Vollenweider (1968) has defined eutrophication of water bodies as ". . .their enrichment in nutrients and the ensuing progressive deterioration of their quality, especially lakes, due to the luxuriant growth of plants with its repercussions on the overall metabolism of the waters affected. . ."

Most lakes and reservoirs originate as water bodies possessing relatively low concentrations of nutrients and generally low levels of productivity. As the water body ages, inflows carry sediment which decreases a water body's depth, and nutrients, which stimulate productivity and further increase the sedimentation rate. Floral and faunal changes occur. Algal blooms become more common, rooted aquatic species increase, and desirable game fish may be replaced by rough fish.

Naturally, this eutrophication process is very slow with the normal life span of a lake being on the order of several hundred years. However, man's practices relating to the disposition of municipal sewage, industrial wastes, and land use cause large nutrient loads on many water bodies. This results in a rapid aging of the lakes and reservoirs and makes the water bodies less attractive to users and, more importantly, shortening the life of the lake or reservoir.

Many different physical, biological, and chemical characteristics are needed to adequately describe a water body's trophic state. There are many indicators of trophic state, each with its merits and shortcomings and many opinions regarding which indicator(s) should be used in classifying lakes and reservoirs. Table 4 lists some of these common indicators or indices. These many indicators of trophic state reflect the multidimensional problem of classifying water bodies and defining its trophic state condition.

The historical aspects and sematics associated with the words "eutrophication," "oligotrophic," "mesotrophic," and "eutrophic" are found in Weber (1907), Naumann (1919, 1931), Thienemann (1918), Rodhe (1969), Hutchinson (1967, 1973), Beeton and Edmondson (1972) and Edmonds (1974).

Table 4

Trophic Indicators Used to Assess Eutrophication[a]

Physical	Chemical	Biological
<u>Morphometry</u> (-)	<u>Chlorophyll a</u> (+)	<u>Algal Bloom frequency</u> (+)
<u>Transparency</u> (-)	Conductivity (+)	Algal species diversity (-)
	Dissolved solids (+)	Bottom fauna (+)
	Epilimnetic oxygen supersaturation (+)	Bottom fauna diversity (-)
	Hypolimnetic oxygen deficit (+)	Fish (+)
	Nutrient concentrations (+)	<u>Littoral vegetation</u> (+)
	Pearsall cation ratio (-)	Primary production (+)
	Sediment type	Photosynthesis (+)

[a] A (+) after an indicator signifies the value increases with eutrophication; a (-) signifies the value decreases with eutrophication. The biological indicators all have associated qualitative changes (i.e., species changes occur as well as quantitative (biomass) changes as eutrophication proceeds). Adapted from Brezonik (1969) Boland (1976), Pearsall (1932), and Wezernak and Palcyn (1972). Remotely sensed indicators are underlined.

WATER QUALITY DATA ANALYSIS

From the very beginning of this study it was apparent that there was a need to provide a more realistic assignment of a water body's trophic condition than the nebulous and overlapping categorizations of oligotrophic, mesotrophic, eutrophic, or hypereutrophic. In a large group of lakes, trophic condition is a continuum with no sharp classes as suggested by these classical groupings.

A relative, numerical trophic state index, based on ground truth survey data was needed to better define trophic condition (i.e., quantitative rather than qualitative).

Description of a lake or reservoir's trophic state requires consideration of several difficult physical, biological, and chemical characteristics, and as such trophic state cannot be directly measured in the field.

Because of the very nature of the multidimensional concept of trophic state, trophic classification lends itself well to two multivariate statistical techniques, cluster analysis and principal component analysis. Brezonik and Shannon (1971) were among the first to apply multivariate techniques in their classification of 55 lakes in Florida.

Thirty-five reservoirs, sampled by the NES in 1973 in the greater Tennessee Valley region, were selected for water quality data analysis. A careful examination of the water quality characteristics measured by the NES and a review of pertinent literature (Boland, 1976; Brezonik and Shannon, 1971; Shannon and Brezonik 1972a, 1972b; Carlson, 1977; Hooper, 1969; Lueschow, 1970; EPA, 1974; and Rast and Lee, 1978) resulted in the selection of six indicators of trophic state: conductivity, µmhos/cm; chlorophyll a, µg/l; total phosphorous, mg/l, total organic nitrogen, mg/l; algal assay yield, dry-weight in mg/l; and Secchi disc transparency, inches. So that all indicators would contribute to the trophic state in a positive sense (i.e., increasing value of indicator being associated with increasing eutrophication) inverse values for Secchi disc depth were used in the data analyses and in development of the trophic state indices for each reservoir. Annual mean values were used in the analyses. A lack of normality in the data necessitated a natural log transformation of the mean values prior to the data analyses. The annual mean values for the six trophic state indicators for each of the 35 reservoirs are given in table 5 with descriptive statistics. Table 6 is a correlation matrix of these six trophic indicators in which the coefficients were determined using natural log transformed data for the 35 NES sampled reservoirs.

Cluster Analysis

Cluster analysis was used to find groupings of reservoirs with similar trophic states, based on the six indicators given in table 5. This study employed the NT-SYS program for complete linkage clustering

Trophic Indicator Data For The 35 Reservoirs Sampled During The National Eutrophication Survey of 1973 in the Greater Tennessee Valley Region

Reservoir Name	Identification Number	Secchi Disc Depth (inches)	Conductivity (µmhos/cm)	Total Organic Nitrogen (mg/l)	Total Phosphorus (mg/l)	Chlorophyll a (µg/l)	Algal Assay Control Yield (mg/l-dry wt.)
Allatoona	GA 1	56.8	40	0.370	0.026	7.5	0.15
Barkley	TN 2	26.6	172	0.263	0.136	12.7	6.40
Barren	KY 3	49.6	206	0.358	0.042	8.0	2.27
Blue Ridge	GA 4	105.1	16	0.209	0.012	3.1	0.10
Boone	TN 5	57.9	174	0.240	0.059	11.4	8.10
Burton	GA 6	136.1	17	0.230	0.008	2.7	0.10
Chatuge	GA 7	117.2	21	0.202	0.016	6.3	0.10
Cheatham	TN 8	26.2	173	0.281	0.145	8.2	8.80
Cherokee	TN 9	51.3	260	0.456	0.068	12.2	2.20
Chickamauga	TN 10	36.2	158	0.218	0.032	3.1	0.45
Cumberland	KY 11	67.6	133	0.212	0.020	3.8	0.10
Dale Hollow	KY 12	170.0	173	0.231	0.012	3.6	0.10
Douglas	TN 13	57.2	184	0.224	0.038	4.6	2.20
Fontana	NC 14	107.4	27	0.251	0.022	3.4	0.10
Fort Loudoun	TN 15	34.4	210	0.350	0.060	4.8	4.10
Great Falls	TN 16	55.6	189	0.319	0.026	4.0	0.10
Guntersville	AL 17	38.9	169	0.326	0.045	8.6	3.70
Hiwassee	NC 18	79.4	32	0.192	0.021	5.7	0.15
Junaluska	NC 19	35.0	106	0.290	0.035	3.2	3.40
Kentucky	KY 20	36.0	148	0.295	0.074	9.2	6.50
Nickajack	TN 21	40.2	164	0.278	0.072	2.7	5.10
Nottely	GA 22	94.3	25	0.180	0.018	6.6	0.10
Old Hickory	TN 23	30.2	139	0.291	0.064	8.9	3.80
Percy Priest	TN 24	69.8	247	0.456	0.094	10.0	3.91
Pickwick	AL 25	49.6	169	0.223	0.056	3.5	8.60
Reelfoot	TN 26	22.1	208	1.694	0.257	81.0	6.40
Santeetlah	NC 27	133.6	17	0.200	0.013	5.4	0.10
Sidney Lanier	GA 28	103.6	35	0.252	0.026	5.4	1.30
South Holston	TN 29	95.2	153	0.253	0.018	7.7	0.10
Tims Ford	TN 30	101.8	137	0.232	0.048	6.7	0.10
Waterville	NC 31	31.7	657	0.565	0.106	3.8	6.40
Watts Bar	TN 32	37.8	176	0.236	0.033	5.6	0.15
Weis	AL 33	21.6	124	0.427	0.095	11.3	6.00
Wilson	AL 34	52.3	172	0.191	0.048	7.4	4.50
Woods	TN 35	70.9	147	0.351	0.021	7.4	0.10
Maximum		170.0	657.0	1.694	0.257	81.00	8.80
Minimum		21.6	16.0	0.180	0.008	2.70	0.10
Mean		65.8	147.9	0.326	0.053	8.67	2.74
Standard Deviation		37.2	113.6	0.254	0.050	12.89	2.92
Median		56.2	155.5	0.260	0.036	6.45	1.75
Skewness		1.0	2.4	4.650	2.317	5.24	0.66

[a] Mean values based on three sampling periods (spring, summer, and fall).

[b] Values based on composite spring samples.

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Table 6

Correlation Coefficient Matrix of Six Trophic State Indicators.[a]

	Inverse Secchi[b]	Conductivity	Total Organic Nitrogen	Total Phosphorus	Chlorophyll a	Algal Assay
Inverse Secchi	1.000	0.634	0.540	0.838	0.456	0.765
Conductivity		1.000	0.481	0.690	0.271	0.600
Total Organic Nitrogen			1.000	0.646	0.677	0.433
Total Phosphorus				1.000	0.613	0.849
Chlorophyll a					1.000	0.412
Algal Assay						1.000

[a]The coefficients were calculated using natural log transformations of the mean data for the 35 National Eutrophication Survey reservoirs sampled in 1973 in the greater Tennessee Valley Region.

[b]The inverse of the Secchi disc depth was used so that all values would increase as the trophic status increases and thus, all be positively correlated.

(Rohlf, Kishpaugh, and Kirk, 1971) using the Euclidian distance to examine the 35 reservoirs sampled during the 1973 NES for natural groupings. The method is also known as the furthest neighbor method. An excellent review of the method is given in Sneath and Sokal (1973).

The results of the cluster analysis are shown as a dendogram in figure 7. The abscissa is the Euclidian distance. On the ordinate axis, the authors have attempted to rank the reservoirs according to trophic state by using stem rotation. In general, the trophic status increases along the ordinate in a upward direction.

What we have attempted to illustrate with figure 7 is that, depending upon the criteria used to define "a cluster," there are certainly more than the three classic states (eutrophic, mesotrophic, and oligotrophic) of reservoir eutrophication and that as the number of reservoirs being considered increases a trophic "continuum" develops. There is some difficulty in reconciling the eight clusters (A, B, C, D, E, F, G, H) with the three classic trophic states. Using NES assessments as a guide: Cluster A may be considered as a very hypereutrophic lake; clusters B, C, and D may be considered as a mixture of hypereutrophic and eutrophic reservoirs; clusters E, F, and G may be considered as a mixture of eutrophic and mesotrophic reservoirs; and cluster H consists of reservoirs characterized as both mesotrophic and oligotrophic.

Principal Component Analysis

Principal component analysis is an ordination technique which in effect reduces the concept of trophic state from six indicators to a single index. In general terms, principal component analysis reduces the dimensions of a concept (eutrophication) by expressing the original observations (six trophic state indicators) in fewer terms (trophic state index). The first principal component (PC1) of a set of variables is the linear combination of the variables which explains the maximum variance in the original data. No absolute physical meaning can be placed on the trophic state index (PC1) values, but the values are felt to have relative meaning and are a quantitative expression of the trophic condition of the 35 reservoirs sampled by the 1973 NES in the greater Tennessee Valley region. The NT-SYS system was used to perform the principal component analysis, (Rohlf, Kishpaugh, and Kirk, 1971). Detailed descriptions of the theoretical and computational aspects of principal components are found in Hotelling (1933a, 1933b, 1936), Anderson (1958), and Morrison (1967).

The normalized eigenvalues and eigenvector numbers are given in table 7. The first component (eigenvector 1) accounts for about 67 percent of the variation in the data. Correlation coefficients between the principal components and the six natural log transformed trophic indicators (table 8) show that the first principal component (PC1) is highly correlated with each of the trophic indicators. From the results shown in tables 7 and 8 it was concluded that the first principal component is indeed indicative of each reservoir's relative position on a multivariate trophic scale.

Figure 7

Dendrogram of 35 reservoirs in the greater Tennessee Valley region sampled by the National Eutrophication Survey during 1973. The dendrogram is based on a complete linkage algorithm using Euclidian distance as the measure of similarity.

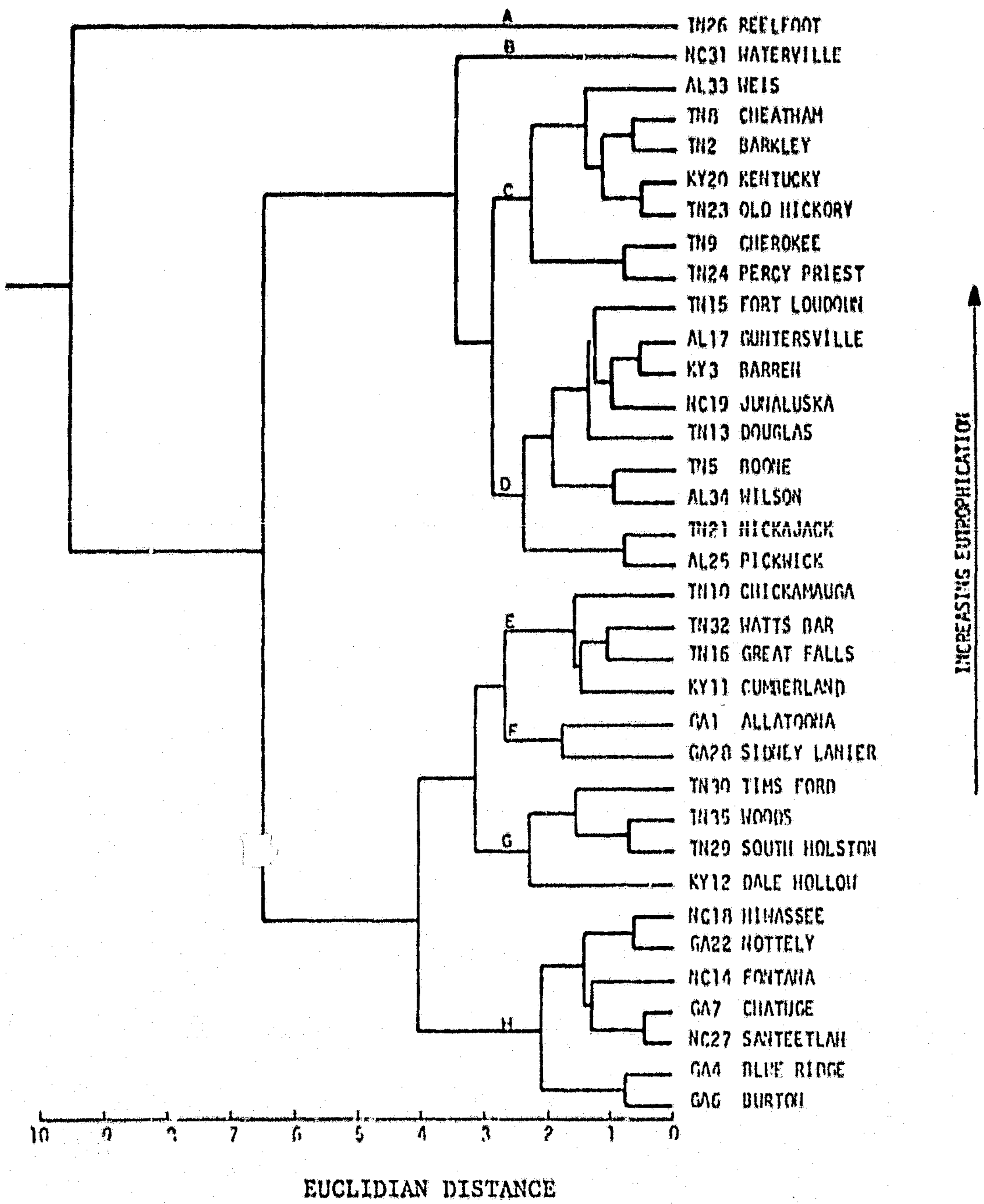

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Table 7

Normalized Eigenvalues and Eigenvectors[a]

Eigenvector Number	Eigenvalue	Variance (%)	Cummulative Variance (%)
1	4.012	66.87	66.87
2	0.921	15.35	82.22
3	0.493	8.21	90.43
4	0.270	4.50	94.93
5	0.218	3.63	98.56
6	0.086	1.44	100.00

[a]The principal component analysis was performed using natural log transformations of mean data for six trophic state indicators (Inverse Secchi, chlorophyll a, algal assay, conductivity, total organic nitrogen, and total phosphorus) for the 35 reservoirs sampled during the 1973 NES in the greater Tennessee Valley region.

Table 8

Correlation Coefficients of Trophic State Indicators and Principal Components[a]

	Principal Component					
	1	2	3	4	5	6
Inverse Secchi	0.879	0.214	-0.141	-0.248	0.312	-0.061
Conductivity	0.755	0.366	0.488	0.231	0.051	-0.040
Total Organic Nitrogen	0.758	-0.472	0.313	0.277	-0.166	-0.022
Total Phosphorus	0.957	0.075	-0.114	0.033	-0.037	0.251
Chlorophyll a	0.682	-0.645	-0.161	0.275	0.117	-0.056
Algal Assay	0.845	0.310	-0.312	0.041	-0.274	-0.121

[a]Correlation coefficients were calculated using the six principal component values and the natural log transformations of the mean values for the six trophic state indicators for each of the 35 NES reservoirs sampled in 1973 in the greater Tennessee Valley region.

The reservoir with the lowest PC1 value, Burton, is rated as having the lowest trophic state of those studied. Trophic state increases in the positive direction with Reelfoot exhibiting the highest trophic state of the 35 water bodies studied. As further evidence that the PC1 values have real meaning, normalized mean composite rank (NMR) indices were calculated and compared as shown in table 9. The NMR's were calculated by ranking each of the six indicators for each reservoir from 1 through 35 and then calculating the average rank for the six indicators at each reservoir. Finally, these averages were normalized. It is quite evident that the NMR and PC1 values results in essentially identical rankings for the 35 reservoirs. This ranking approach has been used in other similar studies (EPA, 1974; Lueschow, 1970; and Piwoni and Lee, 1975).

In conclusion, the PC1's presented in table 9 represent an assessment of each reservoir's relative trophic state and were used as trophic state indices to evaluate Landsat-reservoir eutrophication relationships.

Table 9

Principal Component Value and Normalized Mean Rank Index for 35 Reservoirs Sampled During the National Eutrophication Survey of 1973 in the Greater Tennessee Valley Region

Reservoir Name	Identification Number	PC 1 Value	NMR Index	Position PC1/NMR
Burton	GA 6	-1.441	-1.720	1/1
Blue Ridge	GA 4	-1.274	-1.679	2/2
Santeetlah	NC 27	-1.216	-1.516	3/3
Chatuge	GA 7	-1.051	-1.354	4/4
Dale Hollow	KY 12	-0.970	-1.130	5/7
Fontana	NC 14	-0.960	-1.231	6/6
Nottely	GA 22	-0.957	-1.242	7/5
Hiwassee	NC 18	-0.767	-0.967	8/9
Cumberland	KY 11	-0.612	-1.058	9/8
Sidney Lanier	GA 28	-0.524	-0.702	10/10
South Holston	TN 29	-0.503	-0.590	11/11
Tims Ford	TN 30	-0.368	-0.570	12/12
Allatoona	GA 1	-0.266	-0.041	13/16
Woods	TN 35	-0.264	-0.315	14/14
Great Falls	TN 16	-0.264	-0.132	15/15
Chickamauga	TN 10	-0.153	-0.397	16/13
Watts Bar	TN 32	-0.036	-0.163	17/21
Douglas	TN 13	0.075	0.051	18/17
Wilson	AL 34	0.187	0.092	19/18
Pickwick	AL 25	0.191	0.122	20/19
Junaluska	NC 19	0.258	0.153	21/20
Nickajack	TN 21	0.291	0.214	22/22
Barren	KY 3	0.390	0.743	23/25
Boone	TN 5	0.441	0.712	24/24
Guntersville	AL 17	0.478	0.641	25/23
Fort Loudoun	TN 15	0.530	0.855	26/27
Old Hickory	TN 23	0.581	0.753	27/26
Kentucky	KY 20	0.612	0.967	28/28
Percy Priest	TN 24	0.694	1.109	29/29
Cherokee	TN 9	0.714	1.160	30/30
Cheatham	TN 8	0.908	1.333	31/34
Barkley	TN 2	0.929	1.252	32/3[illegible]
Weis	AL 33	1.004	1.201	33/31
Waterville	NC 31	1.067	1.252	34/3[illegible]
Reelfoot	TN 26	2.278	1.873	35/35

LANDSAT DATA EXTRACTION

Imagery Selection and Manipulation

The extraction of Landsat data for each reservoir required the selection of appropriate dates of imagery, defining the reservoir location on each scene, and then computing the necessary statistics of the raw Landsat data for each reservoir. The computerized data processing portion of this work was performed at the University of Wisconsin, by the Environmental Monitoring and Data Acquisition Group.

Landsat scenes were selected to meet the following criteria: maximum number of reservoirs on the minimum number of scenes; minimum cloud cover; date close to time of sampling; and good quality imagery (figures 8-12). These criteria were difficult to meet and led to poor correlation between dates of Landsat coverage and NES water sampling as no acceptable scenes were found for 1973. On the majority of dates, cloud cover was excessive (greater than 10 percent). Even using scenes with up to 50 percent cloud cover did not provide adequate coverage in 1973. This problem is shared with others, but the Smokey Mountains are in fact deserving of their name.

With the launching of Landsat 2 and the resultant 9-day coverage pattern, adequate Landsat coverage has been received each year since 1975.

The search for Landsat imagery was performed at the EROS Browse File, operated by the TVA Mapping Services Branch, from 16mm microfilm. Computer compatible magnetic tape and black and white photographic products were obtained for the selected scenes. Four sets of tapes were obtained through the courtesy of Oak Ridge National Laboratory and one was obtained directly from the EROS Data Center in Sioux Falls, South Dakota. The scenes selected and used in this study are listed in table 10. The reservoirs which were examined in this study are listed in tables 11 and 12.

The first step in locating each reservoir on a Landsat scene was to construct a grid overlay which could be used to read the Landsat coordinates of any point on the scene. This grid overlay or "pixel counter" was drawn on mylar to fit each frame of Landsat data. It was then possible to find each reservoir on the photographic image and obtain the range of scan lines and elements that would cover that reservoir. This method of determining Landsat coordinates was accurate to approximately 50 pixels.

These Landsat coordinates were used to generate a line printer character plot for each reservoir (figure 13). These plots were for band 7 raw reflectance values. Values of 0-7 were left blank and were used to refine the polygon describing each reservoir, eliminate shadow effects, and to verify the reflectance level for that reservoir.

Figure 8 Reproduction of LANDSAT Multispectral Scanner data, Band 7 (0.8-1.1 micrometers) Frame 1084-15431 (15 October 1972) Identified are classified lakes. Lakes underlined were sampled as part of National Eutrophication Study in 1973.

Figure 9 Reproduction of LANDSAT Multispectral Scanner data, Band 7 (0.8-1.1 micrometers) Frame 1822-15315 (23 October 1974) Identified are classified lakes. Lakes underlined were sampled as part of National Eutrophication Study in 1973.

Figure 10 Reproduction of LANDSAT Multispectral Scanner data, Band 7 (0.8-1.1 micrometers) Frame 1822-15322 (23 October 1974) Identified are classified lakes. Lakes underlined were sampled as part of National Eutrophication Study in 1973.

Figure 11 Reproduction of LANDSAT Multispectral Scanner data, Band 7 (0.8-1.1 micrometers) Frame 1948-15264 (26 February 1975) Identified are classified lakes. Lakes underlined were sampled as part of National Eutrophication Study in 1973.

Figure 12 Reproduction of LANDSAT Multispectral Scanner data, Band 7 (0.8-1.1 micrometers) Frame 2224-15303 (3 September 1975) Identified are classified lakes. Lakes underlined were sampled as part of National Eutrophication Study in 1973.

Table 10

LANDSAT MSS FRAMES

Frame Number	Date	Area	Number of Lakes
1084-15431	15 October 1972	Northeastern Tennessee Western North Carolina	12[b]
1822-15315	23 October 1974	Northeastern Tennessee Western North Carolina	14[b]
1822-15322	23 October 1974	Southeastern Tennessee Western North Carolina North Georgia	15
1948-15264	26 February 1975	Northeastern Tennessee Western North Carolina	15[b]
2224-15303[a]	3 September 1975	Northeastern Tennessee Western North Carolina	15[b]

[a] LANDSAT 2

[b] 10 reservoirs are common to all four scenes. EPA data was collected on 6 of these reservoirs.

Table 11

DATES OF LANDSAT DATA FOR SAMPLED RESERVOIRS

Reservoir Name* and State			15 Oct. 1972	23 Oct. 1974	26 Feb. 1975	3 Sept. 1975
Allatoona	GA	1		X		
Blue Ridge	GA	4		X		
Boone	TN	5	X			X
Burton	GA	6		X		
Chatuge	GA	7		X		
Cherokee	TN	9	X	X	X	X
Chickamauga	TN	10		X		
Douglas	TN	13	X	X	X	X
Fontana	NC	14	X	X	X	X
Fort Loudoun	TN	15	X	X	X	X
Hiwassee	NC	18		X		
Junaluska	NC	19		X	X	
Nottely	GA	22		X		
Santeetlah	NC	27	X	X	X	X
Sidney Lanier	GA	28		X		
Waterville	NC	31			X	
Watts Bar	TN	32	X	X	X	X

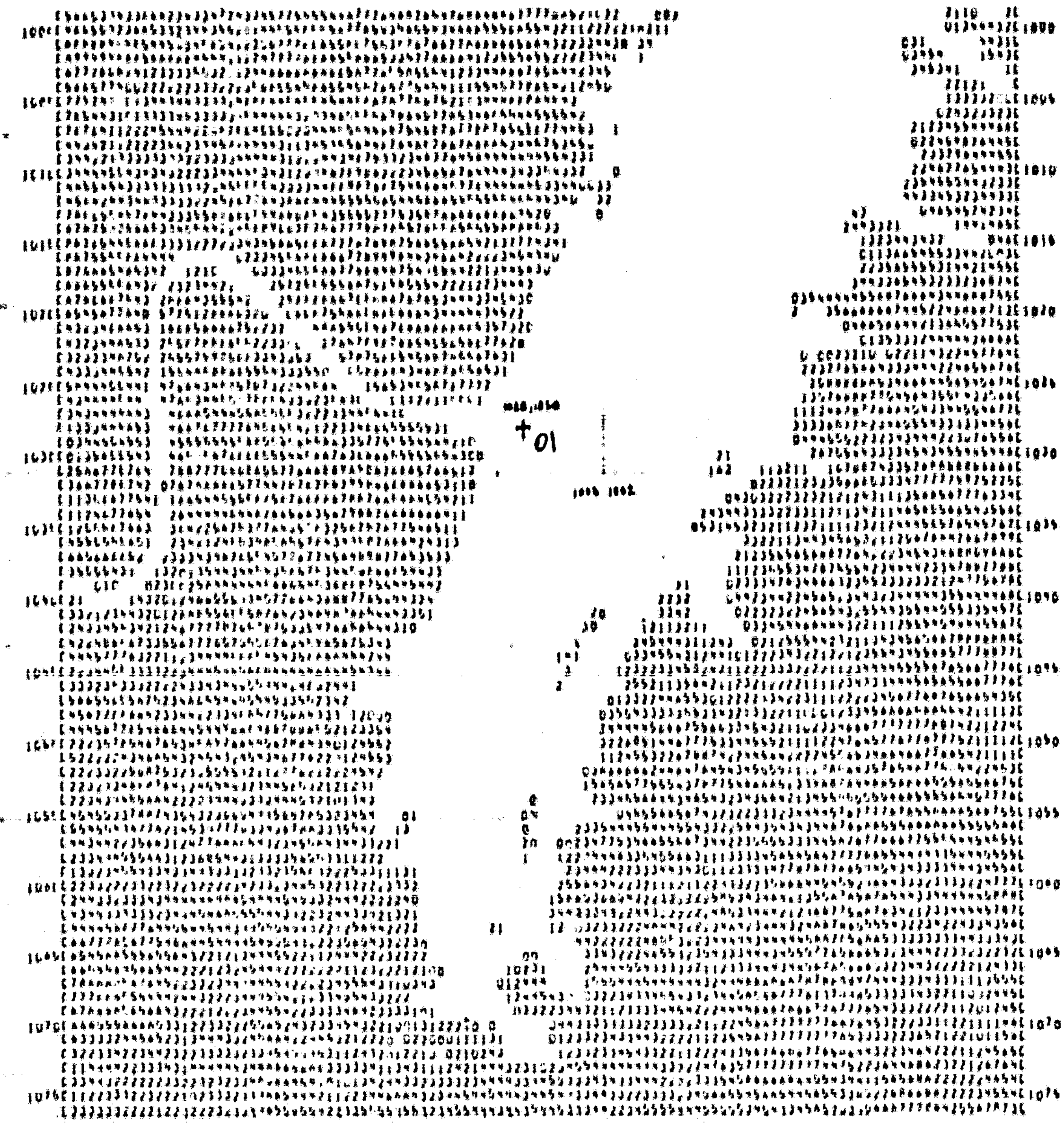
*Reservoirs sampled by the Environmental Protection Agency in 1973.

Table 12

DATES OF LANDSAT DATA FOR NONSAMPLED RESERVOIRS

Reservoir Name* and State			15 Oct. 1972	23 Oct. 1974	26 Feb. 1975	3 Sept. 1975
Carters	GA	1		X		
Chilhowee	TN	2	X	X	X	X
Hartwell	GA	3		X		
Laurel	KY	4		X	X	X
Melton Hill	TN	5	X	X	X	X
Nantahala	NC	6	X			
Nolichucky	TN	7		X	X	X
Norris	TN	8	X	X	X	X
Parksville	TN	9		X		
Rabun	GA	10		X		
Thorpe	NC	11	X	X	X	X
Toxaway	NC	12		X		X
Tuckasegee	NC	13		X	X	X
Tugaloo	GA	14		X		

*Reservoirs included in this study which were not sampled by the Environmental Protection Agency in 1973.



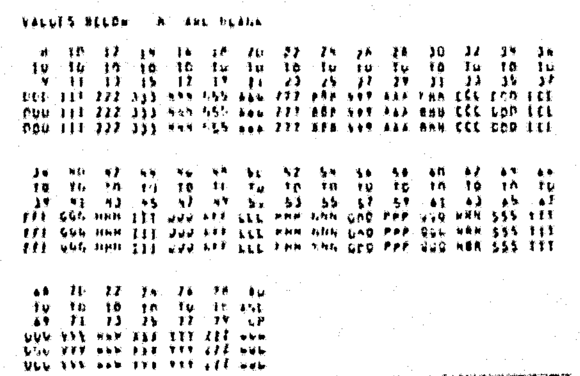


Figure 13: Computer printout of Landsat band 7 density slice. Shown is a portion of Cherokee Reservoir from scene 1822-15315. The area labeled 01 is a NES sample site.

To determine which picture elements were actually in the water a band 7 density slice was made. Only those picture elements with band 7 values of 0-3 were used as representative of water. This relatively low value as compared with those used in other studies (Scarpace 1978, Boland 1976) was necessary for several reasons. This region of the southeast is very rugged with ridges and valleys, which cause significant shadows. These prominent shadows exhibit low reflectance readings that may be confused with water. This effect is reduced using a 0-3 density slice. Another advantage to using the 0-3 band 7 density slice was the elimination of shallow water bottom and shoreline effects. This also resulted in improved correlation between the ground truth water quality data and the MSS data because all NES water samples were collected in deeper water. From inspection of the character plots, all pure water pixels showed reflectance values of 3 or less in band 7.

Generation of Statistics

All picture elements falling within the polygon which generally outlined each lake were extracted from the raw data tape. Of these picture elements, only those with band 7 values between 0-3 were considered in the statistical analysis. Fourteen statistics were determined for each reservoir. These are the mean raw reflectance values for each band (MB4, MB5, MB6, MB7), the variance in each band (VB4, VB5, VB6, VB7), the ratio between band 4 and 5 (RB4), band 5 and 6 (RB5) and band 6 and 7 (RB6), and the variance of these three ratios (VRB4, VRB5, VRB6). The ratios were computed using the following formula:

$$RBi = \frac{255}{\pi/2} \quad \text{ARCTAN}\ (Bi/Bi+1)$$

where

RBi = ratio between band i and i+1
Bi = raw reflectance of band i
Bi+1 = raw reflectance of band i+1

This produces a range in the value of each ratio from 0 to 255 where a change of one unit is always equivalent to the same change in direction in spectral space.

Estimates of three trophic state indicators (Secchi disc depth, conductivity, and total phosphorus) and trophic state indices (PC1) using Landsat and NES ground truth data are demonstrated in the remainder of this report.

In an effort to reduce the amount of data presented in the text, attention has been focused on frames 1822-15315 and 15322. Prior to processing, these two scenes were in actuality one continuous frame recorded on the same orbit. For this reason scenes 1822-15315 and 15322 are treated as one. Regression models and data for frames 2224-15303, 1948-15264 and 1084-15431 are presented in Appendix A.

RELATIONSHIPS BETWEEN TROPHIC STATE INDICATOR AND LANDSAT IMAGERY

Landsat cannot directly measure chemical indicators of water quality but its areal and spectral resolution permit the detection of phenomena indirectly related to eutrophication. In each frame data were extracted for each of the four bands for the NES-sampled reservoirs. The mean and the variance of the reflectance values for each band, and the ratio and the variance of the ratio between bands were calculated. A correlation analysis was performed using this Landsat data and the 15 NES reservoirs in frames 1822-15315 and 15322. Correlations between the Landsat data and trophic state index (PC1), Secchi disc depth, conductivity, and total phosphorus are found in table 13. Several correlation coefficient pairs (e.g., band 6 and Secchi disc depth) exhibit high correlations inferring that relationships do exist between Landsat reflectance values and water quality characteristics.

Data analysis and regression models were developed using the Statistical Analysis System (SAS) (Barr, Goodnight, Sall, and Helwig, 1976); the maximum R^2 improvement technique of the stepwise multiple regression procedure was used to develop multilinear regression models. As such numerous models were developed in this investigation. Criteria used in the selection of the "best" models included R^2 (the magnitude of the square of the multiple correlation coefficient) and the F-statistic. All regression coefficients were required to be significant at the 0.05 level.

Secchi Disc Depth Estimation

The best regression model, as measured by the square of the multiple correlation coefficient (R^2) and the F-statistic, for estimating Secchi disc depth is:

$$\log_e (\text{Secchi}) = 6.282 + 0.142\ \text{MB5} - 0.598\ \text{MB6} + 0.006\ \text{VRB4}$$

The model accounts for about 96 percent of the variance about the mean, table 14. The observed and predicted Secchi disc depth values for the 15 reservoirs are given in table 15.

Although the models presented here are purported to estimate Secchi disc depth, conductivity, and total phosphorus, it must be remembered that the ground truth data collected and Landsat overflight are not concurrent, being separated in time by about one year. This "nonconcurrence" limits the reliability of the models and precludes more precise estimates. Caution must be exercised in assuming that the models are applicable to other reservoirs or even to the same 15 reservoirs on a different date. Reservoirs are by their very nature dynamic. In a period of a few days or weeks, their appearance can change significantly due to algal blooms, turbidity plumes caused by heavy rains, and man induced changes in reservoir volume. In addition to reservoir dynamics are variations caused by atmospheric conditions and solar angle. As such the models should be treated as "ball park" rather than accurate estimators. In fact it is remarkable that estimates are as good as they are and further emphasizes the fact that relationships do indeed exist between water quality characteristics and Landsat imagery.

Table 13

Correlations Between Ground Truth Water Quality Data
and LANDSAT Data for 15 Reservoirs in Frames
1822-15315 and 15322

	PC 1	Secchi	$\log_e$ Conductivity	Phosphorus
Band 4 (MB4)	0.441	-0.547	0.557	0.483
Band 5 (MB5)	0.618	-0.698	0.717	0.643
Band 6 (MB6)	0.808	-0.918	0.863	0.783
Band 7 (MB7)	0.724	-0.853	0.697	0.646
Band 4/Band 5 (RB4)	-0.818	0.831	-0.858	-0.821
Band 5/Band 6 (RB5)	-0.066	0.124	0.028	0.043
Band 6/Band 7 (RB6)	0.386	-0.313	0.408	0.406
Variance Band 4 (VB4)	0.130	-0.366	0.287	0.131
Variance Band 5 (VB5)	0.128	-0.364	0.283	0.128
Variance Band 6 (VB6)	0.118	-0.355	0.273	0.118
Variance Band 7 (VB7)	-0.774	0.794	-0.849	-0.732
Variance Band 4/Band 5 (VRB4)	-0.573	0.582	-0.595	-0.534
Variance Band 5/Band 6 (VRB5)	-0.686	0.705	-0.722	-0.727
Variance Band 6/Band 7 (VRB6)	-0.730	0.771	-0.763	-0.768

Table 14

ANALYSIS OF VARIANCE-SECCHI DISC DEPTH[a]

Source	DF	Analysis of Variance Sum of Squares	Mean Square	F
Regression	3	3.481	1.160	103.98
Residual	11	0.123	0.011	
Total	14	3.604		(R^2 = 0.966)

[a]This analysis was performed using Landsat data from frames 1822-15315 and 15322.

Table 15

SECCHI DISC DEPTH RESIDUALS[a]

Reservoir Name	Identification Number	Observed Secchi Disc Depth (inches)	Predicted Secchi Disc Depth (inches)	Residual Observed-Predicted (inches)
Allatoona	GA 1	56.8	53.1	3.7
Blue Ridge	GA 4	105.1	109.2	-4.1
Burton	GA 6	136.1	127.0	9.1
Chatuge	GA 7	117.2	109.2	8.0
Cherokee	TN 9	51.3	48.1	3.2
Chickamauga	TN 10	36.2	35.8	0.4
Douglas	TN 13	57.2	62.8	-5.6
Fontana	NC 14	107.4	104.6	2.8
Fort Loudoun	TN 15	34.4	31.8	2.6
Hiwassee	NC 18	79.4	90.5	-11.1
Junaluska	NC 19	38.0	39.1	-1.1
Nottely	GA 22	94.3	96.7	-2.4
Santeetlah	NC 27	133.6	111.0	22.6
Sidney Lanier	GA 28	103.6	120.0	-16.4
Watts Bar	TN 32	37.8	42.2	-4.4

[a]This analysis was performed using Landsat data from frames 1822-15315 and 15322.

Conductivity Estimation

The best regression model found for prediction of conductivity is:

$$\log_e \text{(conductivity)} = 6.418 + 1.580\ \text{MB7} - 6.848\ \text{VB7}$$

The model accounts for about 85 percent of the variance about the mean, table 16. The observed and predicted conductivity values for the 15 reservoirs are given in table 17.

Table 16

ANALYSIS OF VARIANCE - CONDUCTIVITY[a]

Source	DF	Analysis of Variance		
		Sum of Squares	Mean Square	F
Regression	2	13.115	6.557	33.14
Residual	12	2.374	0.198	
Total	14	15.489		(R^2 = 0.847)

[a]This analysis was performed using Landsat data from frames 1822-15315 and 15322.

TABLE 17

CONDUCTIVITY RESIDUALS[a]

Reservoir Name	Identification Number	Observed Conductivity (µmhos/cm)	Predicted Conductivity (µmhos/cm)	Residual Observed-Predicted (µmhos/cm)
Allatoona	GA 1	40	65	-25
Blue Ridge	GA 4	16	31	-15
Burton	GA 6	17	21	-4
Chatuge	GA 7	21	33	-12
Cherokee	TN 9	260	124	136
Chickamauga	TN 10	158	213	-55
Douglas	TN 13	184	93	91
Fontana	NC 14	27	27	0
Fort Loudoun	TN 15	210	203	7
Hiwassee	NC 18	32	24	8
Junaluska	NC 19	106	137	-31
Nottely	GA 22	25	17	8
Santeetlah	NC 27	17	13	4
Sidney Lanier	GA 28	35	35	0
Watts Bar	TN 32	176	179	-3

[a]This analysis was performed using Landsat data from frames 1822-15315 and 15322.

Total Phosphorus Estimation

The multiple regression analysis yielded the model:

$$\log_e \text{(total phosphorus)} = 6.889 - 0.060\ \text{RB4}$$

The model explains about 67 percent of the variance about the mean, table 18. The observed and predicted total phosphorus values, along with their residuals, are found in table 19.

Table 18

ANALYSIS OF VARIANCE - TOTAL PHOSPHORUS[a]

Source	DF	Analysis of Variance		
		Sum of Squares	Mean Square	F
Regression	1	3.239	3.239	26.86
Residual	13	1.568	0.121	
Total	14	4.807		($R^2 = 0.674$)

[a]This analysis was performed using Landsat data from frames 1822-15315 and 15322.

Table 19

TOTAL PHOSPHORUS RESIDUALS[a]

Reservoir Name	Identification Number	Observed Total Phosphorus (mg/l)	Predicted Total Phosphorus (mg/l)	Residual Observed-Predicted (mg/l)
Allatoona	GA 1	0.026	0.034	-0.008
Blue Ridge	GA 4	0.012	0.015	-0.003
Burton	GA 6	0.008	0.010	-0.002
Chatuge	GA 7	0.016	0.025	-0.009
Cherokee	TN 9	0.068	0.044	0.024
Chickamauga	TN 10	0.032	0.042	-0.010
Douglas	TN 13	0.038	0.042	-0.004
Fontana	NC 14	0.022	0.017	0.005
Fort Loudoun	TN 15	0.060	0.043	0.017
Hiwassee	NC 18	0.021	0.021	0.000
Junaluska	NC 19	0.035	0.023	0.012
Nottely	GA 22	0.018	0.022	-0.004
Santeetlah	NC 27	0.013	0.016	-0.003
Sidney Lanier	GA 28	0.026	0.013	0.013
Watts Bar	TN 32	0.033	0.038	-0.005

[a]This analysis was performed using Landsat data from frames 1822-15315 and 15322.

Trophic State Index Estimation

The best regression model for the prediction of trophic state index (PC1) values of the 15 NES sampled reservoirs using Landsat data from frames 1822-15315 and 15322 is:

$$PC1 = 4.344 - 0.539\ MB4 + 0.633\ MB5 - 2.511\ VB7$$

The model explains about 88 percent of the variance about the mean, table 20.

Table 20

ANALYSIS OF VARIANCE OF REGRESSION MODEL FOR THE PREDICTION OF THE TROPHIC STATUS OF 15 RESERVOIRS FOUND IN LANDSAT FRAMES 1822-15315 AND 15322

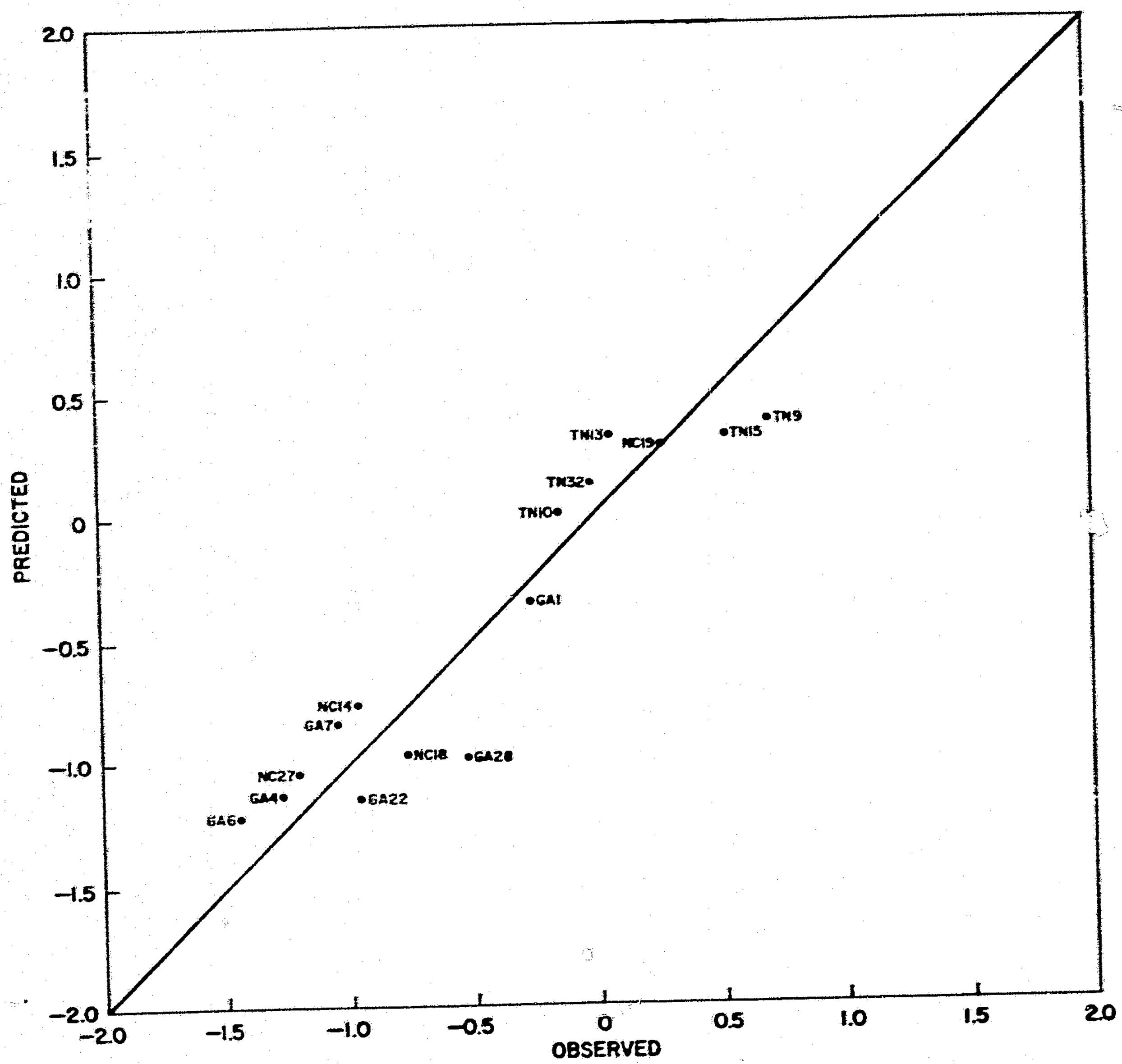
Source	DF	Analysis of Variance		
		Sum of Squares	Mean Square	F
Regression	3	5.826	1.942	27.23
Residual	11	0.785	0.071	
Total	14	6.611		(R^2 = 0.8813)

Keep in mind in examining the above model that the trophic state index (PC1), as well as values for Secchi disc depth, conductivity, and total phosphorus, was developed using mean values of the ground truth measurements taken on three occasions during 1973 while the Landsat data were collected within a few seconds on October 23, 1974.

Figure 14 presents a plot of the observed versus the predicted PC1 values. Those reservoirs plotted to the upper left of the diagonal have been predicted to be more eutrophic than their PC1 values indicate. Reservoirs plotted to the lower right of the diagonal are estimated to be in better condition and less eutrophic than their PC1 values suggest.

When the model was used to predict trophic state index values of reservoirs using Landsat data from another date it produced poor results. However, it is not unreasonable to expect that over a period of time a reservoir would present average reflectance values, which would be more representative of its trophic status. This is one area in which it is recommended that further investigation be performed. The use of reflectance values averaged over several times of the year and corrected for atmospheric differences and solar angle effects, may result in models which could be applied to any reservoir on any given date.

Figure 14



OBSERVED VS. PREDICTED TROPHIC STATE INDEX (PCI VALUES)
FOR 15 RESERVOIRS (LANDSAT FRAMES 1822—15315 AND 15322)

GENERATION OF THEMATIC REPRESENTATION

In order to visually represent the relative trophic state of the reservoirs, a pixel-by-pixel classification of the Landsat imagery was performed. A table-look-up elliptical classifier with a minimum distance to mean option was chosen as the algorithm to perform the classification.

Subsets of Landsat scenes 1822-15315 and 1822-15322 were extracted from the computer tapes which included data from each reservoir to be classified. In all, 28 subsets were extracted and copied onto another tape. A statistics file was generated from the data used in the regression models used to predict the trophic classes. From this statistics file a table was generated to be used by the classifier. Fourteen different classes were represented in the table.

Each of the subsets of the Landsat data were separately classified and files with the results stored on tape. To more easily produce the thematic representation of the reservoirs, the classified data from each scene was combined into two large files. Color separations of each file were produced on an Optronics P-1700 photowrite unit. Some classes were combined to produce a final thematic representation is six colors (figures 15 and 16).

As can be seen in figures 15 and 16, there are variations in the color, representing trophic state, within some reservoirs. These variations do exist, but may be partially due to nonuniformity in the calibration among detectors on the Landsat satellite. The thematic representations are not as good a representation of the trophic state of the reservoirs as the output from the regression models.

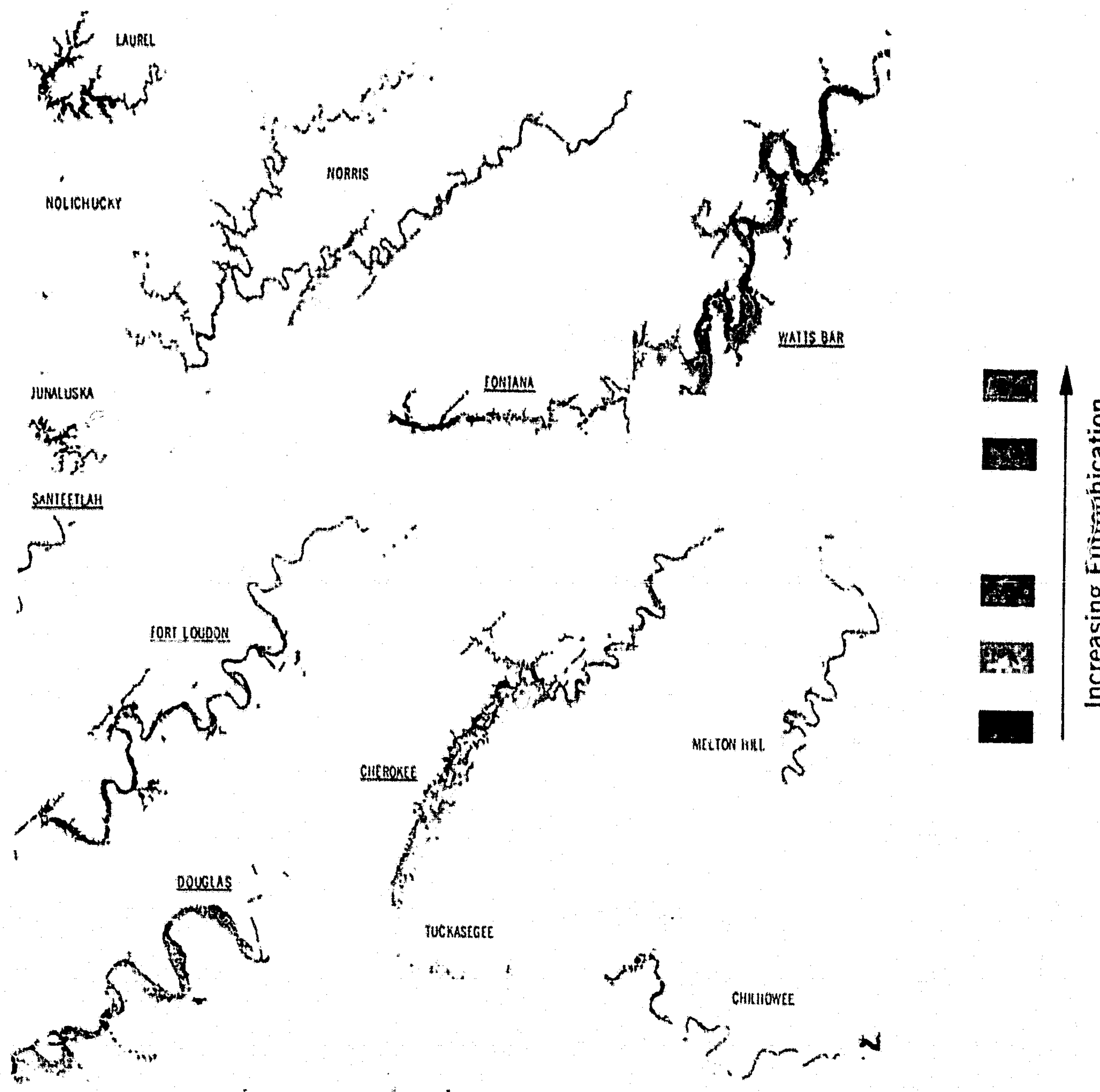


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Figure 15. Color coded thematic representation of the trophic status of selected reservoirs.
(Landsat scene 1822-15322, 23 October, 1974)

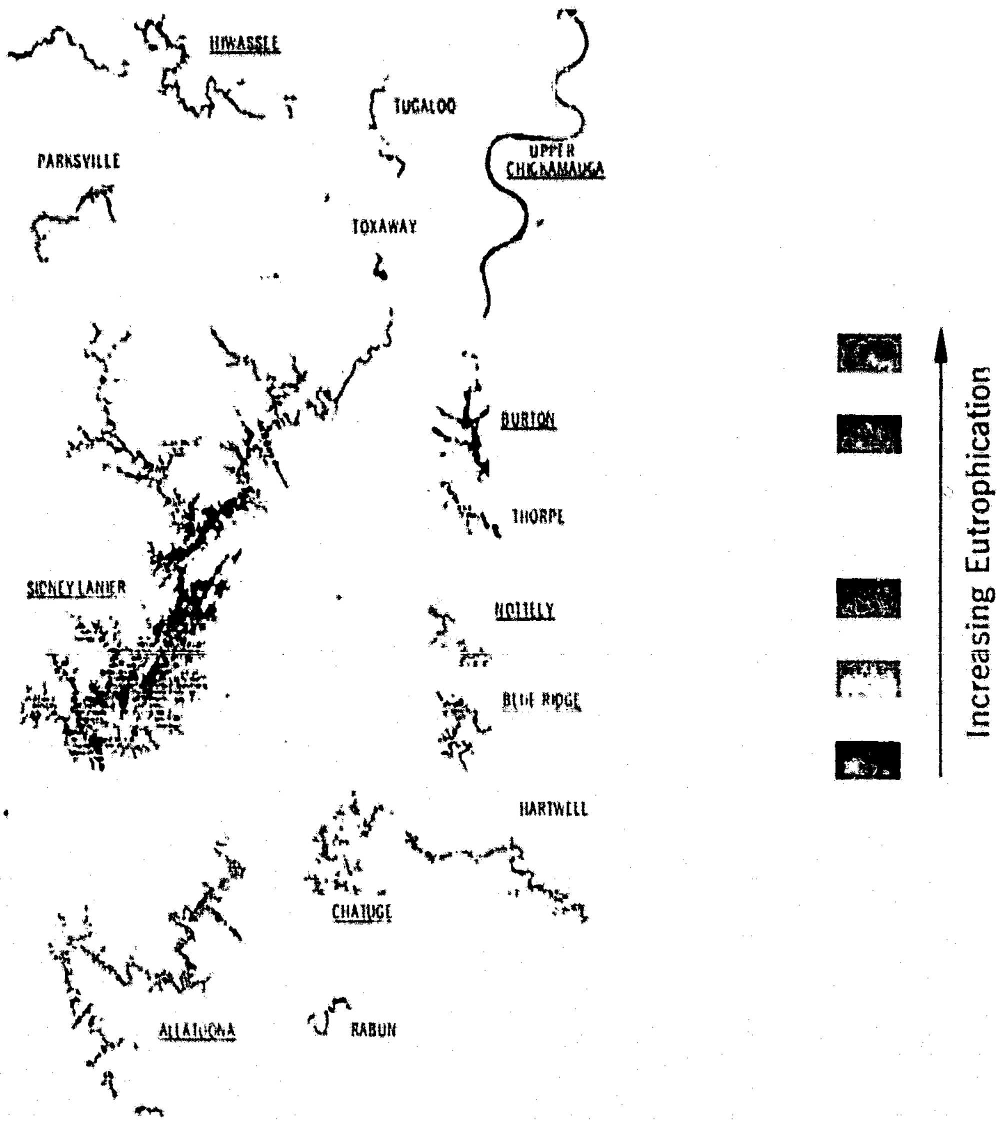

Figure 16. Color coded thematic representation of the trophic status of selected reservoirs.
(Landsat scene 1822 - 15315, 23 October, 1974)

CONCLUSIONS

This study has shown that there is a definite correlation between Landsat reflectance values and reservoir water quality. Correlations between MSS imagery and trophic indicators of reservoirs were often found to exceed 0.95 in several Landsat scenes. This correlation has been demonstrated without the best experimental conditions (no Landsat data within one year of ground samples), further indicating the validity of this technique.

It has been shown that a generalized model can be defined to predict whole lake trophic status (PC1 value) from Landsat MSS reflectance values. Models developed for each of the four Landsat scenes to predict trophic status were all significant at the 0.05 level and in all cases had R^2 values equal to or greater than 0.85. Models were also defined to predict specific water quality parameters of Secchi disc depth, conductivity, and phosphorus content. Finally, color-coded thematic maps were produced showing some of the spatial water quality variance within and between reservoirs.

RECOMMENDATIONS

It is recommended this study be continued so that the following concerns can be further evaluated.

1. Techniques for correcting Landsat data for the effects of atmospheric absorption, scattering, and sun angle changes should be evaluated. If adequate corrections can be made, models may be developed for more than one date or scene, or the same model may be applicable to other dates or scenes. Data has been received to make this evaluation for seven scenes using the ground samples and models presented herein.

2. It is anticipated that much of the variance in these models could be eliminated if ground samples are taken concurrently with Landsat overpasses. This would require a well coordinated sampling program but it should be tried on a demonstration basis.

3. Multiple observations during the growing season have been valuable in other studies (Scarpace et al., 1978) to predict lake trophic status and type of water quality problem. It is recommended that a predictive model which uses multiple data of Landsat imagery during one growing season be evaluated.

4. The primary objective of this study has been to predict whole reservoir trophic status. Further studies should also be made to name and present the water quality changes within particular reservoir areas.

5. In future studies the design of a ground sampling program should strive to produce a more normal distribution. This study was biased toward eutrophic reservoirs.

6. The relationship between landcover and water quality should be investigated using Landsat data.

7. Reservoir data extraction techniques that include geometric overlays based on actually known reservoir configurations should be investigated.

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APPENDIX A

Correlation Coefficients and Regression Models for Landsat Scenes:

1084-15431 (Oct. 15, 1972), Section 1
1948-15264 (Feb. 26, 1975), Section 2
2224-15303 (Sep. 3, 1975), Section 3

Section 1. Scene 1084-15431 (October 15, 1972)

Seven reservoirs were extracted from the frame:
- Boone (TN5)
- Cherokee (TN9)
- Douglas (TN13)
- Fontana (NC14)
- Fort Loudoun (TN15)
- Santeetlah (NC27)
- Watts Bar (TN32)

Table 1.1. Correlation between Ground Truth Water Quality Data and Landsat Data for Seven Reservoirs in Frame 1084-15431

		$\log_e$		
	PC1	Secchi	Conductivity	Phosphorus
Band 4 (MB4)	0.558	-0.812	0.705	0.458
Band 5 (MB5)	0.519	-0.844	0.631	0.441
Band 6 (MB6)	0.263	-0.602	0.354	0.178
Band 7 (MB7)	-0.405	0.229	-0.409	-0.447
Band 4/Band 5 (RB4)	-0.441	0.806	-0.519	-0.389
Band 5/Band 6 (RB5)	0.807	-0.960	0.908	0.767
Band 6/Band 7 (RB6)	0.813	-0.986	0.896	0.737
Variance Band 4 (VB4)	0.030	-0.435	0.229	-0.064
Variance Band 5 (VB5)	0.044	-0.454	0.237	-0.048
Variance Band 6 (VB6)	0.034	-0.423	0.222	-0.051
Variance Band 7 (VB7)	-0.156	0.238	-0.196	-0.102
Variance Band 4/Band 5 (VRB4)	0.188	-0.356	0.181	0.280
Variance Band 5/Band 6 (VRB5)	-0.843	0.897	-0.898	-0.804
Variance Band 6/Band 7 (VRB6)	-0.522	0.764	-0.630	-0.425

The best regression model for the prediction of trophic state (PC1) is:

$$PC1 = 4.420 - 0.286MB6 - 0.012VRB5$$

Table 1.2. Analysis of Variance of Regression Model For the Prediction of the Trophic Status of Seven Reservoirs Found in Landsat Frame 1084-15431

Source	DF	Analysis of Variance		
		Sum of Squares	Mean Square	F
Regression	2	2.898	1.449	12.44
Residual	4	0.466	0.116	
Total	6	3.363		(R^2 = 0.861)

Table 1.3. PC1 Residuals of Seven Reservoirs Found in Landsat Frame 1084-15431

Reservoir Name	Identification Number	Observed	Predicted	Residual Observed-Predicted
Boone	TN5	0.441	0.167	0.274
Cherokee	TN9	0.714	0.558	0.156
Douglas	TN13	0.075	0.507	-0.432
Fontana	NC14	-0.960	-0.600	-0.360
Fort Loudoun	TN15	0.530	0.362	0.168
Santeetlah	NC27	-1.216	-1.353	-0.137
Watts Bar	TN32	-0.036	-0.093	0.057

The best regression model for the prediction of Secchi disc depth is:

$$\log_e \text{(Secchi)} = 25.854 - 0.094\text{RB6}$$

Table 1.4. Analysis of Variance of Regression Model for the Prediction of Secchi Disc Depth of Seven Reservoirs Found in Landsat Frame 1084-15431

Source	DF	Analysis of Variance		
		Sum of Squares	Mean Square	F
Regression	1	1.487	1.487	180.50
Residual	5	0.041	0.008	
Total	6	1.529		(R^2 = 0.973

Table 1.5. Secchi Disc Depth Residuals of Seven Reservoirs Found in Landsat Frame 1084-15431

Reservoir Name	Identification Number	Observed	Predicted	Residual Observed-Predicted
Boone	TN5	57.9	67.2	- 9.3
Cherokee	TN9	51.3	48.9	2.4
Douglas	TN13	57.2	54.4	2.8
Fontana	NC14	107.4	112.4	- 5.0
Fort Loudoun	TN15	34.4	35.8	- 1.4
Santeetlah	NC27	133.6	122.1	11.5
Watts Bar	TN32	37.8	36.0	1.8

The best regression model for the prediction of conductivity is:

$$\log_e \text{(conductivity)} = -11.119 + 0.092\text{RB5}$$

Table 1.6. Analysis of Variance of Regression Model For the Prediction of Conductivity of Seven Reservoirs Found in Landsat Frame 1084-15431

Source	DF	Analysis of Variance		
		Sum of Squares	Mean Square	F
Regression	1	6.019	6.019	23.5
Residual	5	1.280	0.256	
Total	6	7.300		(R^2 = 0.825

Table 1.7. Conductivity Residuals of Seven Reservoirs Found in Landsat Frame 1084-15431

Reservoir Name	Identification Number	Observed	Predicted	Residual Observed-Predicted
Boone	TN5	174	91	83
Cherokee	TN9	260	175	85
Douglas	TN13	184	151	33
Fontana	NC14	27	48	- 21
Fort Loudoun	TN15	210	227	- 17
Santeetlah	NC27	17	17	0
Watts Bar	TN32	176	309	-133

The best regression model for the prediction of total phosphorus is:

$$\log_e \text{(Total Phosphorus)} = 3.490 - 0.188\text{MB4} - 0.014\text{VRB5}$$

Table 1.8. Analysis of Variance of Regression Model for the Prediction of Total Phosphorus of Seven Reservoirs Found in Landsat Frame 1084-15431

Source	DF	Analysis of Variance		
		Sum of Squares	Mean Square	F
Regression	2	2.022	1.011	22.84
Residual	4	0.177	0.044	
Total	6	2.200		(R^2 = 0.919

Table 1.9. Total Phosphorus Residuals of Seven Reservoirs Found in Landsat Frame 1084-15431

Reservoir Name	Identification Number	Observed	Predicted	Residual Observed-Predicted
Boone	TN5	0.059	0.053	0.006
Cherokee	TN9	0.068	0.059	0.009
Douglas	TN13	0.038	0.046	-0.008
Fontana	NC14	0.022	0.026	-0.004
Fort Loudoun	TN15	0.060	0.067	-0.007
Santeetlah	NC27	0.013	0.013	0.000
Watts Bar	TN32	0.033	0.026	0.007

Section 2. Scene 1948-15264 (February 26, 1975)

Eight reservoirs were extracted from the frame:
- Cherokee (TN9)
- Douglas (TN13)
- Fontana (NC14)
- Fort Loudoun (TN15)
- Junaluska (NC19)
- Santeetlah (NC27)
- Waterville (NC31)
- Watts Bar (TN32)

Table 2.1. Correlation between Ground Truth Water Quality Data and Landsat Data for Eight Reservoirs in Frame 1948-15264

		$\log_e$		
	PC1	Secchi	Conductivity	Phosphorus
Band 4 (MB4)	-0.070	0.013	0.026	-0.088
Band 5 (MB5)	0.017	-0.068	0.108	-0.017
Band 6 (MB6)	0.298	-0.339	0.386	0.241
Band 7 (MB7)	0.607	-0.572	0.644	0.616
Band 4/Band 5 (RB4)	-0.098	0.187	-0.141	-0.013
Band 5/Band 6 (RB5)	-0.532	0.449	-0.494	-0.541
Band 6/Band 7 (RB6)	-0.357	0.276	-0.342	-0.423
Variance Band 4 (VB4)	-0.549	0.637	-0.521	-0.394
Variance Band 5 (VB5)	-0.526	0.563	-0.499	-0.368
Variance Band 6 (VB6)	-0.485	0.547	-0.414	-0.333
Variance Band 7 (VB7)	-0.671	0.761	-0.746	-0.570
Variance Band 4/Band 5 (VRB4)	-0.556	0.580	-0.567	-0.393
Variance Band 5/Band 6 (VRB5)	-0.516	0.595	-0.657	-0.510
Variance Band 6/Band 7 (VRB6)	-0.671	0.580	-0.591	-0.434

The best regression model for the prediction of trophic state (PC1) is:

$$PC1 = 5.859 - 0.186MB4 - 0.008VRB5$$

Table 2.2. Analysis of Variance of Regression Model for the Prediction of the Trophic Status of Eight Reservoirs Found in Landsat Frame 1948-15264

Source	DF	Analysis of Variance		
		Sum of Squares	Mean Square	F
Regression	2	3.716	1.858	14.00
Residual	5	0.663	0.133	
Total	7	4.379		($R^2 = 0.849$)

Table 2.3. PC1 Residuals of Eight Reservoirs Found in Landsat Frame 1948-15264

Reservoir Name	Identification Number	Observed	Predicted	Residual Observed-Predicted
Cherokee	TN9	0.714	0.292	0.422
Douglas	TN13	0.075	0.086	-0.011
Fontana	NC14	-0.960	-1.145	0.185
Fort Loudoun	TN15	0.530	0.414	0.116
Junaluska	NC19	0.258	0.041	0.217
Santeetlah	NC27	-1.216	-0.835	-0.381
Waterville	NC31	1.067	1.122	-0.055
Watts Bar	TN32	-0.036	0.456	-0.492

The best regression model for the prediction of Secchi disc depth is:

$$\log_e (\text{Secchi}) = -1.844 + 0.126\text{MB4} + 0.125\text{MB6} + 0.011\text{VRB6}$$

Table 2.4. Analysis of Variance of Regression Model for the Prediction of Secchi Disc Depth of Eight Reservoirs Found in Landsat Frame 1948-15264

Source	DF	Analysis of Variance		
		Sum of Squares	Mean Square	F
Regression	3	1.896	0.632	18.07
Residual	4	0.140	0.035	
Total	7	2.036		($R^2 = 0.931$)

Table 2.5. Secchi Disc Depth Residuals of Eight Reservoirs Found in Landsat Frame 1948-15264

Reservoir Name	Identification Number	Observed	Predicted	Residual Observed-Predicted
Cherokee	TN9	51.3	41.6	9.7
Douglas	TN13	57.2	51.5	5.7
Fontana	NC14	107.4	125.0	-17.6
Fort Loudoun	TN15	34.4	41.8	- 7.4
Junaluska	NC19	38.0	37.2	0.8
Santeetlah	NC27	133.6	117.3	16.3
Waterville	NC31	31.7	33.4	- 1.7
Watts Bar	TN32	37.8	40.4	- 2.6

The best regression model for the prediction of conductivity is:

$$\log_e \text{(Conductivity)} = 13.808 - 0.041\text{RB5} - 0.008\text{VRB5}$$

Table 2.6. Analysis of Variance of Regression Model for the Prediction of Conductivity of Eight Reservoirs Found in Landsat Frame 1948-15264

Source	DF	Analysis of Variance: Sum of Squares	Mean Square	F
Regression	2	9.584	4.792	40.12
Residual	5	0.597	0.119	
Total	7	10.181		(R^2 = 0.941)

Table 2.7. Conductivity Residuals of Eight Reservoirs Found in Landsat Frame 1948-15264

Reservoir Name	Identification Number	Observed	Predicted	Residual Observed-Predicted
Cherokee	TN9	260	149	111
Douglas	TN13	184	287	-103
Fontana	NC14	27	23	4
Fort Loudoun	TN15	210	211	- 1
Junaluska	NC19	106	114	- 8
Santeetlah	NC27	17	22	- 5
Waterville	NC31	657	616	41
Watts Bar	TN32	176	178	- 2

The best regression model for the prediction of total phosphorus is:

$$\log_e \text{(Total Phosphorus)} = 3.521 - 0.238\text{MB4} + 0.091\text{VB4} - 0.009\text{VRB5}$$

Table 2.8. Analysis of Variance of Regression Model for the Prediction of Total Phosphorus of Eight Reservoirs Found in Landsat Frame 1948-15264

Source	DF	Analysis of Variance		
		Sum of Squares	Mean Square	F
Regression	3	2.790	0.930	11.75
Residual	4	0.317	0.079	
Total	7	3.107		($R^2 = 0.898$)

Table 2.9. Total Phosphorus Residuals of Eight Reservoirs Found in Landsat Frame 1948-15264

Reservoir Name	Identification Number	Observed	Predicted	Residual Observed-Predicted
Cherokee	TN9	0.068	0.055	0.013
Douglas	TN13	0.038	0.038	0.000
Fontana	NC14	0.022	0.023	-0.001
Fort Loudoun	TN15	0.060	0.048	0.012
Junaluska	NC19	0.035	0.031	0.004
Santeetlah	NC27	0.013	0.014	-0.001
Waterville	NC31	0.108	0.113	-0.005
Watts Bar	TN32	0.033	0.051	-0.018

<u>Section 3</u>. Scene 2224-15303 (September 3, 1975)

Seven reservoirs were extracted from the frame:
- Boone (TN5)
- Cherokee (TN9)
- Douglas (TN13)
- Fontana (NC14)
- Fort Loudoun (TN15)
- Santeetlah (NC27)
- Watts Bar (TN32)

Table 3.1. Correlation between Ground Truth Water Quality Data and Landsat Data for Seven Reservoirs in Frame 2224-15303

			$\log_e$	
	PC1	Secchi	Conductivity	Phosphorus
Band 4 (MB4)	0.328	-0.619	0.512	0.215
Band 5 (MB5)	0.886	-0.816	0.895	0.826
Band 6 (MB6)	0.596	-0.793	0.746	0.492
Band 7 (MB7)	0.631	-0.4[illegible]4	0.582	0.627
Band 4/Band 5 (RB4)	-0.788	0.941	-0.891	-0.728
Band 5/Band 6 (RB5)	0.349	-0.557	0.520	0.230
Band 6/Band 7 (RB6)	-0.160	-0.080	-0.048	-0.220
Variance Band 4 (VB4)	0.018	-0.420	0.208	-0.072
Variance Band 5 (VB5)	0.018	-0.4[illegible]	0.209	-0.073
Variance Band 6 (VB6)	0.015	-0.418	0.206	-0.075
Variance Band 7 (VB7)	-0.896	0.669	-0.872	-0.872
Variance Band 4/Band 5 (VRB4)	-0.219	-0.223	0.006	-0.310
Variance Band 5/Band 6 (VRB5)	-0.646	0.256	-0.548	-0.672
Variance Band 6/Band 7 (VRB6)	-0.674	0.640	-0.749	-0.585

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The best regression model for the prediction of trophic state (PC1) is:

$$PC1 = 6.127 + 0.006VRB5 - 11.127VB7$$

Table 3.2. Analysis of Variance of Regression Model for the Prediction of the Trophic Status of Seven Reservoirs Found in Landsat Frame 2224-15303

Source	DF	Analysis of Variance: Sum of Squares	Mean Square	F
Regression	2	2.972	1.486	15.20
Residual	4	0.391	0.098	
Total	6	3.363		(R^2 = 0.884)

Table 3.3. PC1 Residuals of Seven Reservoirs Found in Landsat Frame 2224-15303

Reservoir Name	Identification Number	Observed	Predicted	Residual Observed-Predicted
Boone	TN5	0.441	0.254	0.187
Cherokee	TN9	0.714	0.425	0.289
Douglas	TN13	0.075	0.562	-0.487
Fontana	NC14	-0.960	-1.045	0.085
Fort Loudoun	TN15	0.530	0.453	0.077
Santeetlah	NC27	-1.216	-1.069	-0.147
Watts Bar	TN32	-0.036	-0.031	-0.005

The best regression model for the prediction of Secchi disc depth is:

$$\log_e (\text{Secchi}) = -8.959 + 0.083\text{RB4}$$

Table 3.4. Analysis of Variance of Regression Model for the Reduction of Secchi Disc Depth of Seven Reservoirs Found in Landsat Frame 2224-15303

Source	DF	Analysis of Variance: Sum of Squares	Mean Square	F
Regression	1	1.354	1.354	38.80
Residual	5	0.175	0.035	
Total	6	1.529		(R^2 = 0.886)

Table 3.5. Secchi Disc Depth Residuals of Seven Reservoirs Found in Landsat Frame 2224-15303

Reservoir Name	Identification Number	Observed	Predicted	Residual Observed-Predicted
Boone	TN5	57.9	68.5	-10.6
Cherokee	TN9	51.3	55.6	- 4.3
Douglas	TN13	57.2	41.0	16.2
Fontana	NC14	107.4	99.9	7.5
Fort Loudoun	TN15	34.4	36.5	- 2.1
Santeetlah	NC27	133.6	128.2	5.4
Watts Bar	TN32	37.8	43.4	- 5.6

The best regression model for the prediction of conductivity is:

$$\log_e \text{(Conductivity)} = 12.002 - 0.001VB4 - 11.561VB7$$

Table 3.6. Analysis of Variance of Regression Model for the Prediction of Conductivity of Seven Reservoirs Found in Landsat Frame 2224-15303

Source	DF	Analysis of Variance		
		Sum of Squares	Mean Square	F
Regression	1	7.028	3.514	51.84
Residual	4	0.271	0.068	
Total	6	7.299		(R^2 = 0.963)

Table 3.7. Conductivity Residuals of Seven Reservoirs Found in Landsat Frame 2224-15303

Reservoir Name	Identification Number	Observed	Predicted	Residual Observed-Predicted
Boone	TN5	174	143	31
Cherokee	TN9	260	241	19
Douglas	TN13	184	268	-84
Fontana	NC14	27	24	3
Fort Loudoun	TN15	210	176	34
Santeetlah	NC27	17	21	- 4
Watts Bar	TN32	176	176	0

The best regression model for the prediction of total phosphorus is:

$$\log_e \text{(Total Phosphorus)} = 0.324 - 5.569\text{VB7}$$

Table 3.8. Analysis of Variance of Regression Model for the Prediction of Total Phosphorus of Seven Reservoirs Found in Landsat Frame 2224-15303

Source	DF	Analysis of Variance		
		Sum of Squares	Mean Square	F
Regression	1	1.671	1.671	15.84
Residual	5	0.528	0.106	
Total	6	2.199		(R^2 = 0.760)

Table 3.9. Total Phosphorus Residuals of Seven Reservoirs Found in Landsat Frame 2224-15303

Reservoir Name	Identification Number	Observed	Predicted	Residual Observed-Predicted
Boone	TN5	0.059	0.047	0.012
Cherokee	TN9	0.068	0.060	0.008
Douglas	TN13	0.038	0.063	-0.025
Fontana	NC14	0.022	0.020	0.002
Fort Loudoun	TN15	0.060	0.051	0.009
Santeetlah	NC27	0.013	0.018	-0.005
Watts Bar	TN32	0.033	0.027	0.006

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